TEACHERS COLLEGE RECORD

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THE TEACHING OF PHYSICAL SCIENCE

Given a class all the members of which are the same age, all having taken the same previous studies, all having the same standing, and all good in mathematics, they will still be found to be widely different in their capacity to understand physics. The difference among them lies not in their mental calibre, but in the experiences they may have had, or rather in the attention they may have paid to their experiences. There are high-school pupils who have had no conscious experience that would lead them to think that they could secure a mechanical advantage by taking hold of the long arm of a lever. Such pupils often go through the usual quantitative experiments in the laboratory as though they were exercises in pure mathematics. They seem to add nothing to their physical sense. They are no more likely to feel that they could move a log better by taking hold of the end than by seizing it in the middle; they see no reason why a heavy object may be rolled up a gradual incline more easily than up a steep one, or, for that matter, why it would not be better to lift it without an inclined plane. They have no instinct, when walking by the side of a railroad track, which would lead them to prefer the inside rather than the outside of a curve when a train is coming. They see no reason why a river should gouge the outer rather than the inner bank on its winding course. They see no reason why a pro-

peller wheel should cause an airship to move, It is not to them self-evident that if rapidly moving air knocks a building over the air must have weight. If when looking obliquely upon the surface of a quiet lake they see a bright star reflected therein, they do not know by experience where to look for the star itself. These are not rare cases. A majority of the students who come to the study of physics feel that a large portion of the common everyday material phenomena is "uncanny." The first purpose of a beginning course in physics, whether in grammar school, high school, or college, should be to make nature and her ways seem *natural.* It matters little whether we call it nature-study phenomenology, or physics (all of which terms are in reality synonymous as applied to elementary work); we must lay the foundation for an understanding of our subject by furnishing a basis of experience, comparing observation with observation, lighting one fact with another. This does not necessarily mean laboratory work, although that may be made a most fruitful aid.

It would seem self-evident that the first thing one must do is to find out the exact mental equipment of his students—to find out what the foundation is before he begins to build upon it. But the schools are full of persons just out of college, teaching not the pupils, but their own self-respecting course in physics. These straightway reach the conclusion that few students are fit to take physics.

The writer believes that there is nothing in the nature of physics nor in the nature of either grammar-school or high-school pupils which precludes their studying physics; on the other hand, it would seem evident that the subject is peculiarly well suited to fit them for life. This view seems to be generally accepted by the public and most children seem to have the desire for a knowledge of things physical so strongly implanted in them that they will study it after a fashion in spite of the delinquencies of the schools. No distaste for the physics of the schoolmaster has in the slightest degree affected their love for the physics of everyday life.

The first requisite of a high-school teacher of physical science is that he should have that grasp of his subject and that understanding of pupils that would enable him to teach his subject with equal facility to any and all persons from twelve to eighteen years of age.

Apparently not more than 5 or 6 per cent of all the high schools in the United States have a sufficient number of teachers so that one may give his whole attention to physical science, including physics and chemistry, and not more than 2 or 3 per cent have teachers who may specialize between physics and chemistry. This does not appear to be a misfortune. A rather careful and extended investigation of the matter has brought me to the conclusion that the best teachers of any science are those who are fairly well trained in all rather than those who have had training in one science only. The high-school teacher of physical science needs at least a general college course of one year's duration in each of the following: physics, chemistry, and biology. It is desirable that he have a second year's course in each of the first two. But it is of the utmost importance that these courses be given him by a model teacher and that he be associated with those who are looking forward to teaching rather than to research. He should have also a course in the history of physical science and in the teaching of the same. He should gain a knowledge of the modern trend of teaching in his field by a study of the papers read at educational meetings and discussions published in educational journals during the past fifteen years. He should read the prefaces of a dozen or more of the high-school text-books in physical science. These have been written for the most part by the most successful teachers of the time, selected by rather astute publishing houses who keep a close watch upon the field and generally know what is most likely to meet the demand. Each author in his preface has attempted to state what are his ideals. To read these prefaces and to scan through the texts is one of the best ways to discover what are the aims and tendencies of the teaching of physical science for any period. And a clear understanding of the trend of the immediate past will enable one to predict what will be the practice of the near future.

The intending teacher should be familiar with the various syllabuses put forth in his subjects and the examination questions upon his subjects which have been given high-school graduates for the past few years. These will indicate the scope of the subject as it is in the mind of some of those who are in a position to direct the teaching of physics. Visits to schools, inspection of equipment, and talks with teachers are a necessary part of

the education of the intending teacher. The reports of city and state superintendents often contain very instructive matter for intending teachers.

During the college course most young men suffer a complete internal revolution. Senior conservatism takes the place of freshman enthusiasm, but it is still counterfeit. Their excesses are quite as great, but they are of a negative kind. Finding that much which they had affirmed is untenable, they now deny everything. Being unable longer to believe all things, they disbelieve all things. If they have chosen science as their major study, they affect to discount all other subjects of study. They sometimes show contempt for poetry, art, music, literature, philosophy, religion, women, and people in general outside of their department. Their elders, thinking that all this is merely a phase of adolescence, are more or less complacent about it, but I cannot feel that they are yet suitable material for high-school teachers. There is still a capacity for worship in them, and it is directed toward science and the great scientists. Like most worshippers, they conceive their gods to be like themselves, and it is a very great and wholesome eye-opener to them to learn that Faraday, Maxwell and a host of other masters of science have been devoted to religion, that Davy, Maxwell, and many others living and dead have been poets, artists, musicians, philosophers, husbands, fathers, and even men of the world. It is a distinct shock to the youthful specialist of to-day to learn that none of the great scientists have been specialists in early life. On the contrary, their interests often seem to have been particularly diffuse. Poetical imagination rather than mathematics seems to have been a conspicuous foundation in many of them. Huxley was a great reader of novels, and Simon Newcomb wrote one. It is well that a young man before he goes into high-school teaching should get over his cant about scientific accuracy and truthfulness, and learn that the physicists are no better and no worse than other people, no more accurate and no more reliable in their judgments when outside of their particular field. A man trained to scientific conservatism in one subject may be a wild cat in some other.

If one would really know what is the condition of things at the present time, in which he is living, and what is to be the condition of things in the near future, for which he should prepare to live,

let him regard more than the ephemeris of to-day. He should study the trend of the recent past and thus divine both the true present and the near future. Let us see what authors of text-books and other persons who have commanded more or less attention have to say about vitalizing the teaching of physics by the use of practical applications and interpretations of the phenomena of everyday life; about the use of the inductive method; about the infusion of mathematics into physics; about quantitative work; about lectures; about simplification of the subject and of the apparatus.

In 1857, in the preface of his "Natural Philosophy," Wells wrote: "The principles of physical science are so intimately connected with the arts and occupations of everyday life, with our very existence and continuance as sentient beings, that public opinion at the present time imperatively demands that the course of instruction in this subject shall be as full, thorough, and complete as opportunity and time will permit. The author has endeavored to render the work eminently practical, the illustrations and examples have been derived, in most cases, from familiar and common objects."

Of the fifty or more high-school texts which have been written during the past fifty years, there is scarcely one that has not reiterated this sentiment in its preface. When, however, we come to look into the body of the text we are invariably disappointed. Those who have written during the last fifteen years have noticeably been circumscribed in this matter. To take a single example, Wells under the head of "Strength of Materials" gives an interesting and illuminating account covering eight pages. Hollow bones of animals, hollow stalks of grains, and hollow columns in buildings are discussed among other interesting things. Within the last fifteen or twenty years, however, the exigencies of college preparation have substituted for all this a laboratory exercise in which each pupil attempts to find the number of grams required to break a piece of small wire. We certainly need common-sense instruction about strength of material. Many a man has stripped the screw thread from some fine piece of apparatus before he learned that brass was a softer metal than steel and could not be safely handled with a monkey wrench. To many persons all metals are hard and strong and able to stand any

abuse, until they have learned to the contrary by some unnecessarily bitter experience. Certainly whatever we may profess in the prefaces of our text-books, we are actually doing less in our schools to-day than we did fifty years ago to make sciences minister to the needs of our common life. The fact that it requires a pull of a certain number of grams to break a piece of No. 24 brass wire is of no concern to any of us—not even to the bridge builder. It would seem that laboratory teachers, like kindergarten folks, have been at much pains to invent "busy work."

Previous to 1870 there was much in the way of "philosophical apparatus" in the schools, and in the hands of many a skillful demonstrator and true teacher it served admirably to make knowledge real. As early as 1837 the city of Boston furnished each of its grammar schools with a set of physical apparatus costing $275 for each set. A similar set was to be found in most of the academies of the country about that time, and there are a large number of persons now living who are both capable and willing to testify that they received more that was worth while from the instruction given with the aid of that apparatus than our high schools of to-day are giving under the college-entrance requirements.

Between 1870 and 1880, much was said about the value of individual laboratory work and the use of the inductive method. In 1872 Eliot and Storer in the preface to their "Elementary Manual of Chemistry" wrote: "The authors' object is to facilitate the teaching of chemistry by the experimental and inductive method, to develop and discipline the observing faculties." Storer and Lindsley somewhat later said: "The student acquaints himself with facts and principles through attentive use of his own perceptive faculties."

From 1873 to 1878, Steele wrote in his prefaces to books on chemistry and physics: "Unusual importance is given to that practical part of chemical knowledge which concerns our everyday life." "A closer relation between school room, kitchen, farm, and shop." "The author has used simple language and practical illustrations (and the student) is at once led out into real life. From the multitude of principles, only those have been selected which are essential to the information of every well-read person." "Aim to lead young persons to become lovers and in-

terpreters of nature." "Simple experiments within the reach of every pupil at home." "The text-book only introduces the student to a subject which he should seek every opportunity to pursue." "As far as possible every question and principle should be submitted to nature for a direct answer by means of an experiment." And in no other books have I found the text fulfilling so completely the promise of the preface, as in his.

In 1881, Avery's "Chemistry" said: "As far as possible the experiments are to be performed by the pupil rather than for him." In 1882, Gage's "Physics" had stamped upon the cover "Read nature in the language of experiment." The preface quotes from Superintendent Seaver of Boston: "The mind gains a real and adequate knowledge of things only in the presence of the things themselves." Gage remarks that chemistry has been taught by the laboratory method for twenty years, and urges the introduction of laboratory work in physics. In the English High School in Boston, he had with $300 furnished a laboratory which answered the requirements of a large school. He proposes fifteen as the size of a laboratory class and five experiments in an hour— twelve minutes to an experiment including the writing of the notes upon the same. "Laboratory practice and didactic study should go hand in hand, and divide the time with one another about equally." "So far as practicable, experiments precede the statements of definitions and laws, and the latter are not given until the pupil is prepared, by previous observation and discussion, to frame them for himself." Gage stood for greatly simplified apparatus.

Trowbridge, head of the Department of Physics at Harvard, in his high-school text-book in 1884 said:

"The writer believes that the necessary amount of geometry and trigonometry (for the study of physics) can be taught at about one sitting."

"It is necessary for the student of science to obtain a certain balance of judgment, and to cultivate a certain scientific instinct."

"Physics should not be made a means of teaching mathematics. I have, therefore, substituted experimental problems for the mathematical problems which are usually given in treatises on natural philosophy, in the hope of cultivating the scientific instinct."

"The natural progress of our study of any subject is from the qualitative, or the comparatively rough evidence of our senses, to the quantitative."

"The author recommends that from one to two lectures be given during the week. In these lectures the experiment should be performed which the students afterward perform themselves in the laboratory."

H. N. Chute, "Practical Physics," 1899:

The teacher is recommended to first perform experiments in the presence of the class; the laboratory work should follow.

"The office of the school laboratory is not one of original discovery, but to put the student in the best possible position to see what he looks at."

"The student always finds that the close contact with the experiment in the laboratory reveals to him enough that he did not see when he witnessed it in the class room to compensate him many times over for the time he now has put upon it."

Mr. Chute recommends simple apparatus.

"The verification and the illustration of Nature's great laws require no elaborately finished and expensively constructed appliances."

At Ann Arbor High School he began with an appropriation of $100 and added to the equipment by a small fee which each student paid.

Hall and Bergen, 1891:

Previous to 1886 candidates for entrance to the freshman class at Harvard had been examined on text-book work only. In this year a laboratory requirement was added.

"An attempt was made to bring together such experiments as would have the most frequent and important application in ordinary life."

Hall and Bergen, Revised and Enlarged Edition, 1897:

"The instruction should direct especial attention to the illustrations and applications of physical laws to be found in everyday life."

"The pupils' laboratory work should give practice in the observation and explanation of physical phenomena."

Hall suggests simple apparatus. He proposes about $1,000 to equip a laboratory with apparatus for twelve workers and for teachers' demonstrations.

Allen, 1892:

"Unless the instructor assures himself before each exercise that the pupils understand what they are to do and how to do it, they may make wreck of the whole exercise."

"When entirely new or especially complicated apparatus is to be used, I find it advisable to place a 'dummy' before the class and require pupils to go through the motions with it, to answer questions on the general method and the special manipulations, and, in case of a complicated calculation, to work out results from imaginary data."

"Since the instructions in one subject do not assume a previous knowledge of any other, there is nothing to prevent the subject's being taken up in any order desired."

"The relative order of text-book and laboratory work will naturally depend upon the nature of the subject. Sometimes laboratory work precedes class room work and sometimes the reverse."

Carhart and Chute, 1892:

"The laboratory method has come in during the past decade." They describe very clearly how the inductive method or attempt at it results in failure.

"A few years ago it seemed necessary to urge upon teachers the adoption of laboratory methods to illustrate the text-book; in not a few instances it would now seem almost necessary to urge the use of a text-book to render intelligible the chaotic work of the laboratory."

"The pupil should be kept in his class-work well ahead of the subjects forming the basis of his laboratory experiments."

Avery, 1895:

"The class-room work must be kept ahead of the laboratory work; i. e., the pupil must come to the laboratory with some knowledge of the principles involved in the work that he is required to perform."

He does not appear to think that high-school pupils can work by the inductive method.

Cooley, 1897:

"The student should study the text book before entering the laboratory."

The order recommended is:

"(1) Oral instruction—involving illustrative experiments. (2) The study of a text-book. (3) Laboratory work to practice experimental methods of reaching or testing truth."

Nichols, 1897:

" In the selection of the methods and of the apparatus I have had in view the greatest possible directness and simplicity, rather than the highest degree of accuracy."

Crew, 1899:

" Physics, in too many of our schools, ranks as a most difficult subject. But dealing, as it does, with the familiar phenomena of daily life, and requiring, as it does, only a small fraction of the algebraic knowledge which the average student has already acquired, the author is inclined to believe that the difficulty lies chiefly in the presentation."

"An elementary presentation of physics should begin by resuming what might be called the experience of the average lad of sixteen years. The number of physical facts which a boy of this age has accumulated is astounding. Seldom, indeed, does the instructor appeal to him in vain for a verification of an elementary fact. The demand therefore is not so much for new facts, or for sheer facts of any kind, as for an orderly arrangement and an ability to use these facts."

Hortvet, 1899:

" It is found in practice that the purely inductive method fails at points where it is expected to do the greatest amount of good."

Roland and Ames, 1899:

" The phenomena of physics are too complicated to be described by any student left unaided, or to be understood when demonstrated, unless he is guided by a suitable text-book containing the theory of the subject. In other words, physics must first be taught in the class room, where the student may see demonstrated and explained those experiments on which the science is based. To teach physics without lecture experiments is almost worse than useless. For a student beginning the subject, laboratory instruction in physics is of secondary importance. It is extremely useful and a great aid to the student in understanding the subject. If possible, however, laboratory work should be required of all students; and the experiments should be in the main quantitative. All the principal facts and theories of physics should be illustrated by lecture experiments."

" It is possible by means of exceedingly simple apparatus to illustrate nearly all the elementary laws and facts of physics. This should be the purpose of the lecture."

Torrey, " Chemistry," 1899:

" Chemistry has suffered from the irrepressible wave of laboratory madness which has swept over the whole educational world."

"Nothing too severe can be said against the mechanical and demoralizing system of note-books with 'operation,' 'observation,' and 'inference' headings. They are wholesale breeders of dishonest and superficial work."

Thwing, 1900:

"Laboratory work should follow the study of text."

Henderson and Woodhull, 1900:

"Physics should be so taught as to be a desirable and even essential subject for every pupil in the secondary schools."

"The relations of physics on all sides to human life and human interests have been emphasized."

"The laboratory deals with inductions and verifications, and its chief purpose is to make knowledge *real*."

"Both laboratory and class-room work are essential to a correct knowledge of elementary physics, and they should correlate."

"Portraits and brief sketches of men who, by their researches, have contributed much to our knowledge of physics have been introduced."

Nichols, Smith, and Turton, 1901:

It is a laboratory manual only. Chiefly quantitative. Some exercises, however are qualitative. The authors state that "the qualitative experiments performed by the pupil himself will frequently appeal to him in a way that is absolutely impossible if performed by the teacher."

Sanford, 1902:

"Training in scientific method, induction, etc. Lecture-room method poorest of all methods."

Slate, 1902:

"My experience proves beyond reasonable doubt that elementary instruction in physics suffers where contact with phenomena and with experimental methods is confined to a small group of quantitative experiments; the possibilities of the class (lecture?) experiment have not been fully exploited."

"Instead of feeding them with crumbs from the specialists' table, physics for the school must be treated in relation to the average boy and girl, approaching the threshold of active life."

Holden—"The Sciences," 1902:

"Main object, to help the child to understand the material world about him. Why should not natural phenomena be comprehended by the child?"

"It is not possible to explain every detail of a locomotive, but it is perfectly practicable to explain its general principles."

"The plan is to waken the imagination; to convey useful knowledge; excite a living and lasting interest in the world that lies about us."

"Familiar phenomena are referred to their fundamental causes."

Coleman—"Laboratory Manual," 1903:

"The laboratory course should stand in co-ordinate relationship to the work of the class room; which should include as important elements qualitative experimental work by the teacher, the systematic study of a good text-book, as large a use of reference books as time and opportunity permit, a constant appeal to the everyday experiences of the pupils, and finally, the recitation or quiz, in which the information gleaned from the several sources is classified, organized into scientific knowledge, and assimilated."

"This point of view presupposes that the laboratory work will, in general, precede the recitation, but may itself be preceded by experimental work by the teacher, presenting fundamental phenomena as an introduction to either the qualitative or quantitative work of the laboratory. It is also assumed that the text-books and reference books are legitimate aids towards the interpretation of the experiment *while it is being performed,* and that the reading of the text on the subject of the experiment before the laboratory hour will economize time in the laboratory and lead to the best results."

"The course includes many valuable qualitative experiments."

Andrews and Howland, 1903:

"We have sought to make prominent the practical bearings of physics. To those students at least whose schooling ends with the high school, physics should be a connecting link between their study and their work. Except in special cases it bears more on the daily affairs of life than any other subject."

Bits of history are introduced to show the close relation between the science of physics and human life.

"The student should constantly keep in mind that the data of physics are much easier to remember if they are interpreted in terms of past experiences, everyday events, and that such interpretations are far more valuable than the mere acquisition of data."

Higgins, 1903:

"Presents an elementary view of physics and its practical application."

Short biographical sketches of scientists at the end of the book.

Hopkins, 1894:

"The work is quantitative throughout. Qualitative work in the physical laboratory is of little or no value as training for the beginner."

The work deals chiefly with mechanics for the reason that in that subject "it is possible to obtain results which differ not more than one per cent. from the true values."

"In some other branches of the subject, I have not found this to be the case. For this reason I have omitted all work upon specific heat, latent heat, velocity of sound and measurement of wave length of sound. I have omitted all work upon electric currents and electro-magnetism for two reasons: First, because there is scarcely a boy now in school who has not considerable practical elementary knowledge of these subjects; and, second, because I have found that such experiments serve more for the entertainment and amusement of the student than for his instruction."

"The subject of Light, also, is one which for similar reasons, I prefer to leave untouched in this course; but as some of the experiments in this subject admit of accuracy, I have added a few. I believe, however, that this course will be found sufficiently complete without them."

"The course has been given with good success without recitations or class-room work of any kind."

"A section of twelve is as large as one instructor can properly take care of. Still better work will be done if two instructors are available for a section of fifteen to twenty students."

Culler, 1905:

Says nothing about practical applications in the preface but makes much use of them in the text.

Mann and Twiss, 1905:

"The aim has been to show the student that knowledge of physics enables him to answer many of the questions over which he has puzzled long in vain."

"Beginning arguments with inventions, or general observations of phenomena, may not be the logical order, but it is more nearly the order in which Nature herself teaches, and the result of the argument does not lose in definiteness, clearness, or accuracy, provided the laboratory is continually held up as the final court of appeal where all doubtful questions are settled."

"Each chapter is a continuous argument toward some principle or principles, and the entire book is an argument toward the conclusions stated in the last chapter," which are in part: "It must be clear to every one who has read this book carefully

that nature is not a vast chaos of chance happenings, but a well ordered and governed whole. When we study thoughtfully the phenomena about us, we must realize that there are some simple and universal principles which are manifest in them all. The universe in which we live is a marvelously organized and governed unit and we are compelled to recognize that it could not have organized itself solely by the interaction of blind matter and undirected motion."

"The attempt is made (1) to interest the student in observing carefully and accurately first the familiar things about him and then the things in the laboratory; (2) to interest him in detecting analogies and similarities among the things observed; (3) to train him in keeping his mind free from bias and in drawing conclusions tentatively; (4) to make him see the value of verifying the conclusions and accepting the result whether it confirms or denies his inference."

"We have tried deliberately to give the student the impression that science leads to no absolute results—that, at best, it is merely a question of close approximation; of doing the best we can, and accepting the result tentatively, until we can do better. This attitude places the teacher also in the position of a learner and prohibits him from making use of didactic or dogmatic statements; for these are the bane of science as well as of other things. Science instruction that does not develop mental integrity, freedom of the personal judgment, and tolerance, fails in a vital spot."

"References are given to books in which the biographies of the great men of science may be read, and the student is urged to read them and report. The arguments used by some of the great thinkers have been briefly sketched, and the methods devised by them for reaching conclusions have been given. The attempt has been made to present them as they live in the ideas which they have handed down to us; to picture their mental processes and attitudes, and to show how one thing leads to another as the subject develops in the discoverer's mind."

Cheston and others, 1906:

"It is recognized by all as a sound pedagogical principle that laboratory work performed by the pupil should constitute his introduction to each new subject or principle."

Coleman, 1906:

"The subject-matter has been selected with reference primarily to its value as a part of a general education, and includes an unusual amount of information based upon the facts of our daily experience, introduced as illustrations and applications of physical principles."

"Physics deals largely with familiar natural phenomena and is therefore of special interest and profit as a part of a general education." "A very important part of the material is acquired through the experiences of our daily life."

Milliken and Gale, 1906:

"The book attempts to give a simple and immediate presentation, in language which the student already understands, of the hows and whys of the physical world in which he lives."

"In the description and illustration of physical appliances the course has been made unusually complete because that is what the student is most eager to learn but cannot obtain from books because their language is too technical for him."

The portraits of sixteen of the great makers of physics have been inserted "for the sake of adding human and historic interest."

William Allanach—"Elementary Lessons in Magnetism and Electricity," London, 1906:

"The author believes that the tendency in some recent books of striving for apparently accurate results so as to appeal to the student, is much to be deprecated, resulting as it frequently does in 'fancy' experiments which give a spurious semblance of accuracy. A little careful and honest thinking is worth much of it."

Hoadley, 1908:

"Especial effort has been made to lay proper emphasis upon the application of physics in everyday life."

"Simple apparatus. Most of the experiments are for demonstration to the class, performed by teacher or chosen pupils."

"With a superabundance of excellent material within the scope of elementary physics, there would seem to be no valid reason for spending the first days in the laboratory on manipulation and measurement with vernier and micrometer calipers, the diagonal scale, the spherometer, etc., as is sometimes done with no physics in sight."

"The more simply and directly a physical problem is presented to the pupil the better, that his thoughts and attention may not be diverted from the real point at issue. This principle is especially applicable in the early part of the laboratory course, where it is most frequently and most seriously violated by the use of micrometric instruments, the Jolly balance, etc., in the work on density and specific gravity, even before the pupil has had practice in the simpler methods of measuring and weighing. It would seem as if the express purpose of such work were at the outset to throw as many obstacles in the way of progress in physics as the ingenuity of teachers and instrument makers could devise."

" Perhaps the most striking illustration of what should not be done in this respect is afforded by the familiar quantitative experiments on the breaking strength of wires and on elasticity of stretching, bending, and twisting. These experiments lead absolutely to nothing in most high-school courses. The laws with which they deal are, for the most part, not considered in elementary text-books."

" The qualitative experimental study of phenomena rightly deserves a large place in an elementary physics course. Economy of time and equipment, convenience, and the advantage of the superior skill of the teacher, are considerations in favor of presenting much of this material in the form of class-room experiments; but in a great many instances the laboratory experiment, affording, as it does, immediate sense perception of the phenomena in their simplest aspects and at close range, is greatly superior to any experiment viewed at a distance, and a laboratory course which fails to take this into account is necessarily one-sided and incomplete."

" Experiments should be regarded as a limited inquiry into the facts at first hand, not as sources of adequate data for generalization by the pupil, nor as ' verifications ' of the laws and principles stated in the text. The pupil's experiment is not a proof of the law, but an aid to the right understanding of it."

" What the pupil really does is to perform an experiment which within a fair degree of accuracy, illustrates or exemplifies the law; and he does this in order that he may the better understand it, not because the law is in need of ' verification.' "

" To encourage the pupil to draw hasty and unwarranted conclusions from insufficient data is a vicious practice."

Adams, 1908:

" Physics deals with phenomena in which every child is interested; it treats of subjects with which all men and women have more or less to do in practical life."

Crew and Jones, 1909:

"Appeal to the everyday experience not only of boys but also of girls—show them physics as a science of daily life—assist the pupil in explaining the material phenomena of the world about him."

It is interesting to turn back and see what views were expressed on the teaching of physics nearly a century ago.

" Elements of Physics " by Dr. Neil Arnott, London, was written the same year that Faraday inaugurated his celebrated lectures to children at the Royal Institution (1826–27). The introduction contains the following:

"Mathematics are at present generally made the beginning of the study, and the reason assigned is that scarcely any object in physics can be described without referring to quantity or proportion, and therefore, without using mathematical terms. Now this is true; but it is equally true that the mathematical knowledge, acquired by every individual in the common experience of childhood and early youth, is sufficient to enable students to understand all the great laws of nature."

"Most persons find attention to pure or abstract mathematics as irksome as the study of mere vocabulary of a language. This explains why so small a proportion of students, if taught in the common way, become good mathematicians, and why, where pure mathematics are made the avenue to Natural Philosophy, this also is so much neglected. It is remarkable how much the really simple and attractive science of comparing quantities has been rendered terrible to the great mass of mankind."

"The mode of proceeding is just as if a man, to whom permission were given to enter and possess a magnificent garden, on condition of his procuring a key to open the gate and measures of all kinds to estimate the riches contained within, should waste his whole life on the road in polishing one key, or in procuring several of different materials and workmanship, and in preparing a multiplicity of unnecessary measures."

"That the importance of physics has not been marked by the place which it has held in common systems of education, is owing chiefly (1) to the misconception that a knowledge of technical mathematics was a necessary preliminary, and (2) to an opinion that the degree of acquaintance with physics which all persons acquire by common experience, is sufficient for common purposes."

"To a man who understands the simple truths of physics very many phenomena, which to the uninformed appear prodigies, are only beautiful illustrations of his fundamental knowledge—and this he carries about with him, not as an oppressive weight, but as a charm supporting the weight of other knowledge, and enabling him to add to his valuable store every new fact of consequence which may offer itself."

"It has been a common prejudice that persons thus instructed in general laws had their attention too much divided, and could know nothing perfectly. The very reverse, however, is true; for general knowledge renders all particular knowledge more clear and precise."

"No treatise on Natural Philosophy can save, to a person desiring full information on the subject, the necessity of attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external

senses, leave on the memory much stronger, and more correct impressions, than where the conceptions are produced merely by verbal description, however vivid. And no man has ever been remarkable for his knowledge of physics who has not had ***practical familiarity*** with the objects."

Among the typical lessons to be found on page 40 of this issue of THE RECORD, I have reproduced, as worthy of imitation to-day, Arnott's method of presenting Newton's third law.

Of the numerous books on Natural Philosophy, intended for school use, written before Arnott's, several are of great interest, but the only one to be mentioned here is that by Ferguson written about seventy-five years before Arnott's book—about 1750. This book passed through many editions. In 1805, it was revised by David Brewster of Edinburgh, who will be recalled as the biographer of Sir Isaac Newton. The next year it was revised and brought out in America by Robert Patterson, Professor of Natural Philosophy at the University of Pennsylvania.

Brewster says, "The chief object of Mr. Ferguson's labors was to give a familiar view of physical science and to render it accessible to those who are not accustomed to mathematical investigation."

"Mr. Ferguson may be regarded as the first elementary writer on natural philosophy, and to his labors we must attribute that general diffusion of scientific knowledge among the practical mechanics of this country, which has, in a great measure, banished those antiquated prejudices and erroneous maxims of construction that perpetually mislead the unlettered artist."

"No book upon the same subject has been so generally read, and so widely circulated, among all ranks of the community. We perceive it in the workshop of every mechanic. We find it transferred into the different encyclopædias which this country has produced, and we may easily trace it in those popular systems of philosophy (natural philosophy, i. e., physics) which have lately appeared."

Mr. Ferguson, although wholly a self-educated man (having had only about three months of schooling), was elected a member of the Royal Society of London. His lectures were frequently attended by the King, who pensioned him in his latter years.

"He possessed a clear judgment and was capable of thinking and writing on philosophical subjects with great accuracy and precision. He had a peculiar talent for simplifying what was

complex, for rendering intelligible what was abstract, and for bringing down to the lowest capacities what was naturally above them."

It is interesting to note that Ferguson devotes sixty-two pages to machines in those days when there were exceedingly few machines, and his treatment of the principles of machines is surpassingly clear; whereas in our age of machinery when every boy and girl needs to know much about the principles of machines and their practical applications in daily life, this subject is certainly most meagerly treated in text-books and altogether the most poorly taught portion of the whole subject of physics.

Ferguson devotes forty pages to pumps and, although he was writing before oxygen was discovered and before the steam engine was invented, he gives a most fascinating account of a "fire-engine," as he calls it, which, however, we should call a steam pump, or more specifically the atmospheric steam engine.

Among the typical lessons to be found on the later pages of this issue of THE RECORD, I have thought it would be not only interesting, but even suggestive of a good method of teaching a subject to-day, to reproduce Ferguson's treatment of "The Spring of the Air."

Pestalozzi died in the year that Arnott wrote his "Natural Philosophy," and about that same time the "Lessons on Objects" written by Elizabeth Mayo was beginning to attract the attention of educators in London.

These "Object Lessons" ran through fourteen editions in London during the next thirty years, and finally the book was revised and brought out in this country by Dr. Sheldon of Oswego, who had as his collaborator Professor Hermann Krusi, also teaching at Oswego, but who was born in the school of Pestalozzi, where his father taught for twenty years.

Physics teaching in the high schools, before the colleges took a hand in the matter in 1886, was powerfully influenced by this movement to teach from the object rather than from the book and to take into consideration the nature and requirements of the pupil when making a choice of matter and method of instruction.

"In 1837 the School Committee of Boston ordered a few articles of philosophical apparatus to be furnished for each of the grammar schools of that city." The above appears in the preface of "A

School Compendium of Natural and Experimental Philosophy," written by Richard Green Parker, Principal of Johnson Grammar School. The book was written to go with the Boston set of apparatus. It contains engravings of the apparatus and a description of experiments to be performed with it. This Boston set consisted of nearly one hundred pieces and cost $275. The book went through twenty-two editions in the first twelve years and was still being revised as late as 1854 at least.

Very respectable equipment for the teaching of physics was to be found in academies and high schools all over the country soon after this and there were numerous firms (even more numerous than now) in Boston, New York, and Philadelphia, whose business it was to manufacture and sell apparatus for the schools.

This apparatus was used for demonstration purposes by the teachers who were usually the principals of the schools, and for the most part good teachers. They applied a large amount of common sense to the teaching of physics and with a large personal influence they impressed the pupils with the dignity and importance of the subject. There are many now living who are in position to speak of the effect of this instruction and compare it with that which now obtains. I am gathering such testimony and shall be glad to hear from any who may read this.

That the subject was very widely taught might be inferred from the great demand for text-books which appeared almost as frequently fifty years ago as now and passed through in some cases an astonishing number of editions. The aim of the instruction in physics fifty years ago was generally stated to be the interpretation of the natural phenomena of life. It must be confessed that the writers of text-books in those days about as often as in these days failed to carry out this idea in the body of their texts. But I am of the opinion that the teachers of those days, more often than the teachers of to-day, carried that purpose into effect, the chief reasons being (1) a large proportion of them had received training directly from nature's school. A goodly number of them had college training, to be sure, but so far as it had touched them on the side of science it had led them to nature rather than away from it. (2) They were unhampered in their teaching by any prescription from a higher institution made in the supposed interests of something or somebody else than the pupils themselves.

In 1838, Olmsted's "Natural Philosophy for Schools and Academies" stated the purpose to give an "exhibition of the principles of Natural Philosophy with very copious applications of them to the arts and to the phenomena of nature."

In 1847, Dr. John W. Draper, Professor at New York University, wrote his "Natural Philosophy for Schools." He preferred to begin with air and water rather than mechanics because the latter "is a more difficult and more forbidding subject." He says:

"The main object of a teacher should be to communicate a clear and general view of the great features of his science, and to do this in an agreeable and short manner. It is too often forgotten that the beginner knows nothing; and the first thing to be done is to awaken in him an interest in the study, and to present to him a view of the scientific relations of those natural objects with which he is most familiar. When his curiosity is aroused, he will readily go through things that are abstract and forbidding, which, had they been presented at first, would have discouraged or perhaps disgusted him."

"There are two different methods in which Natural Philosophy is now taught; (1) as an experimental science; (2) as a branch of mathematics. I believe that the proper course is to teach physical science experimentally first."

"Why is it that the most acute mathematicians and metaphysicians the world has ever produced for two thousand years made so little advance in knowledge, and why have the last two centuries produced such a wonderful revolution in human affairs? It is from the lesson first taught by Bacon, that so liable to fallacy are the operations of the intellect, experiment must always be the great engine of human discovery, and, therefore, of human advancement."

Loomis—"Natural Philosophy," 1858:

"Natural Philosophy has long been regarded as forming an essential part of a course of liberal education, and every year it is becoming more generally introduced into academies and high schools."

"While the leading object has been to teach general principles, care has been taken to combine with them a variety of useful information and particularly to give an account of many recent discoveries in every branch of the science."

Quackenbos—"Natural Philosophy," 1859:

"The importance of the physical sciences is now so generally admitted that there are few institutions of learning in which they are not made regular branches of study."

"Exhibiting the applications of scientific principles in every-day life."

"Illustrating them fully with the facts of our daily experiences."

Hooker—"Natural Philosophy for Schools," 1863:

"Daniel Webster, in his autobiography, speaks thus of his entering upon the study of law:

'I was put to study in the old way—that is, the hardest book first—and lost much time. I read Coke on Littleton through without understanding a quarter of it. Happening to take up Espinasse's "Law of *Nisi Prius*," I found I could understand it; and arguing that the object of reading was to understand what was written, I laid down the venerable Coke *et alios similes reverendos*, and kept company for a time with Mr. Espinasse and others, the most plain, easy, and intelligible writers. Why disgust and discourage a boy by telling him that he must break into his profession through such a wall as this?'"

"Here is most graphically depicted a defect which is now, as it was then, very prominent in all departments of education."

"In the books which are used in teaching natural science, it is especially prominent. Even in the elementary books, formal propositions and technical terms render the study uninviting, and to a great extent unintelligible."

"In the whole course of education, the natural sciences should be made prominent from the beginning to the end, not only because they are of practical value, but also because they are as useful in their way for mental discipline as the study of mathematics and of language."

"They can be taught to some extent to the youngest pupils, if they be presented in the right manner. And the busy inquiries which they make after the reasons of the facts, and their appreciation of them if stated simply and without technical terms, show the appropriateness of such teaching. Children are really very good philosophers in their way. They have great activity not only of their perception but of their reasoning faculties also, to which due range should be given in education. Not a year should pass during the whole course when the pupil shall not be engaged in studying some one of the physical sciences to some extent."

"The teaching of the natural sciences in our colleges is generally a failure, and it always will be so as long as the present plan is continued. In order to have it successful there must be the same *gradation in teaching them that we have in teaching language and the mathematics.*"

Rolfe and Gillet, 1868:

"There is, as there ought to be, a rapidly increasing demand on the part of the public that the study of natural philosophy shall be introduced into our Grammar and District Schools."

"The authors believe that the subject is both such as every one ought to know about, and such as can be profitably treated in a sufficiently elementary form for the use of these schools."

"The authors believe that in teaching the sciences the aim should be, not so much to present facts and the bare statement of principles, as to train the mind to see how from the simple facts of observation we arrive at the principles of science."

"First establish the facts by experiment and then draw out the principle."

"Use simplest experiments and simplest apparatus."

"Each lesson is to be explained and illustrated with the class before being given out to be studied."

There were many other writers of books of Natural Philosophy for the schools, but enough has been quoted to show the trend. In this connection it will be to the point to quote something from John Tyndall's lecture delivered in 1854 at the Royal Institution of Great Britain on "Physics as a Branch of Education for All."

"The needs and tendencies of human nature express themselves through the early yearnings of the child. He desires to know the character and the causes of the phenomena presented to him; and I claim for the study of Physics the recognition that it answers to an impulse implanted by nature in the human constitution, and he who would oppose such study must be prepared to exhibit the credentials which authorize him to contravene Nature's manifest design."

"Most of the questions asked by children concern natural phenomena, facts of everyday life. Now the fact is beyond the boy's control, and so certainly is the desire to know its cause. The sole question then is, Is this desire to be gratified or not? Who created the fact? Who implanted the desire? Certainly not man—and will any man undertake to place himself between the mind and the fact, and proclaim a divorce between them?"

"Every physician knows that something more than mere mechanical motion is comprehended under the idea of healthful exercise. What, for example, could be substituted for the jubilant shout of the playground? You may have more systematic motions. You may devise means for the more perfect traction of each particular muscle, but you cannot create the joy and gladness of the game, and where these are absent, the charm and the

health of the exercise are gone. The case is similar with mental education."

"In the study of Physics, induction and deduction are perpetually married to each other."

The following is from Thorndike's "Principles of Teaching" (page 157):

"The verification of conclusions is the keynote of correct inductive thinking in the world at large, and should be more prominent in the school. The common practice of children is to accept as true whatever the teacher does not oppose. This is not so bad as it may seem, for 'to be accepted by the expert' is a sort of verification well known and not despised by science, and to the scholar the teacher stands *'in loco experti'* * * * and recourse to other authorities than the teacher provides useful experience of the bulk of expert knowledge which is stored up in dictionaries, encyclopædias, maps, books, and the like."

McMurry in his "Special Methods in Science," after stating what have been the various aims in science teaching (such as: teaching observation; understanding and mastering the physical conditions of life-utility; mental discipline; classification—system and law), proposes as a suitable aim, *insight into nature, a sympathetic appreciation with a view to a growing adjustment to* the physical and social environment. He adds: "The intrusive and masterful way in which natural science has been coming into our houses, factories, and industries of all sorts, compels us to pay considerable attention to the applications of science to life."

The idea which has been most consistently and uniformly expressed in all the prefaces of text-books already quoted is *vitalize the teaching of physics, teach its applications to life.* From examination of the texts themselves it appears to be in the minds of all of the authors that the method should be, first, teach the principles, and second, mention applications as we teach rules of grammar, and illustrate by giving sentences from literature. At any rate, so far as any attempt to actually teach the applications of physical principles to life is made, this is the method used and this is precisely why the teaching of physics is languishing. The number of so-called principles has been doubled and even quadrupled since the days of Ferguson and Arnott, and the colleges at present specify by syllabus a long list of those which the candidate must be able to demonstrate like propositions

in geometry. The method of teaching physics—no matter how much laboratory work it may include—does not differ essentially from the method of teaching geometry. Only the case is worse for physics than for geometry. For in geometry, there is a mutual dependence of one proposition upon another, but in physics, in spite of the efforts of one or two authors to the contrary, there never has been, and I presume there never can be, an organized whole to physics which will appeal to the mind of a high-school pupil. The fundamental idea which may be assumed to run through it all will always be found too subtle and too profound for his comprehension. To him Boyle's law is never related to anything else in physics; and if on college-entrance examination he does not state the law of Charles for that of Boyle, it is a sheer piece of good luck; for that matter, if he does not make up an entirely new law by stating parts of each, it is only his good fortune. And, why should he remember the vast number of strange and unrelated facts or principles—unrelated to each other and unrelated to any experience in his life? Even the laboratory illustrations given him, ostensibly for the purpose of throwing light on the principles, are like an attempt to define one unknown word by another equally unfamiliar.

Now to illustrate each principle by referring it to some one of life's experiences would be a great step in advance, but to turn the method of procedure around and develop only such principles as grow out of and interpret life's experiences would be not only ideal but, in the nature of the case, the only method which can be successful.

One cannot help thinking that if the high-school teachers of the country had been as free to work out their method of instruction as the elementary-school teachers have been during the last twenty years, they would have learned to apply to physics the modern, yet abundantly tried and eminently successful, method of teaching language to small children.

This matter is so well stated by McMurry in his "Special Methods in Science" that I cannot do better than to quote him. It will be noticed that McMurry is here speaking of the teaching of science in the elementary school—what some call nature-study; but I am wholly in agreement with Professor Bailey that nature-study is not a new subject but a new mode of teaching, which

is just as applicable to the high school and the college as to elementary schools.

"A child does not want the alphabet (that is, the simple principles) of science any more than he wants the names of the letters of the alphabet when learning to read."

"What he needs is to observe more closely and to put things together for better interpretation."

"There is another great advantage in teaching science where we find it in these centers of life's activity, and not in some isolated scientific form in laboratories or text-books."

"The child who draws his knowledge of science directly from life, under normal conditions, will not have much difficulty in finding it again in life and applying it to life. It is not difficult to so isolate the study of physics and chemistry from the usual conditions of life that the student in after years will have more difficulty in rediscovering his knowledge than he had in first acquiring it. But the child who learns from the start to trace facts to their native lair will recognize them again under similar surroundings. In the usual study of the natural sciences, each science centres its materials around its leading principle, but from the home as a centre radiate problems into all the sciences. Ventilation is based on physics and physiology; cooking on chemistry and several other sciences. House sanitation draws from most of the sciences. Heating and lighting carry us into several fields of applied science. In later years he may devote himself to a study and ordering of one or more of the separate sciences, but their chief merit after all will be the service they are able to render to these original centres of human interest. If we should take each of the natural sciences as a controlling centre of study we should have a complicated and difficult, if not impossible, course of study. Elementary science more perhaps than any other study is home-abiding and begets respect and admiration for common things."

"As a rule teachers are over-hasty in urging children toward generalizations. They wish them to leap from one or two facts or examples to important conclusions of classifications."

"Teachers and adults are prone to give emphasis to general laws far beyond what children need."

"The applications of science to life have so transformed our surroundings that we live in a very different world from that of fifty years ago. To live properly in this new world is to understand it, to fit into it and to make the best use of it. Since the changes are due chiefly to scientific inventions and improvements, progress in education calls for a direct and more partial acquaintance with sciences by common people."

"The problem of object and experiment teaching is the most highly recommended and the least successfully practiced phase of instruction. The freedom and confidence with which teachers, high and low, recommend observational and experimental science, and the modesty and scarcity of those who succeed in such teaching is an illustration of the wide breach between enthusiastic theory and successful practice."

Dr. James E. Russell in the December 1909 issue of the *Educational Review* says: "Bookish work when properly understood is above criticism. In so far as the aim of learning is to acquire knowledge there is no good reason for spending an hour in manipulation when the fact may be as well taught without it in a minute." I am very sure that a large portion of the hours now spent in the laboratory might with profit all around be contracted to an equal number of minutes spent with books, but better than that they might be much expanded and profitably expended in getting together, comparing and explaining the experiences which pupils have or may have under proper guidance.

Let there be, however, vastly more—ten times as much—reading on the subject as now. Let there still be a laboratory for personal contact with things and for large measurements—pounds and feet—such as ordinary people use.

The quantitative treatment of the subject belongs quite as much to the lecture as to the laboratory. The process of vitalizing physics gets small assistance from the conventional laboratory work—indeed, the demonstration of physical principles is not much forwarded by the laboratory measurements. It is not only possible, but usual, that students lose the rationale of the whole subject under consideration by laboratory work which has lost none of its distractions in the recent attempts to make it rigorous.

I am sure that Draper was right when he said that the subjects with which to begin the teaching of physics are water and air. A considerable portion of that which usually precedes this subject should be omitted from a high-school course and much of the rest should be brought in incidentally and scattered among the other subjects. What remains might form a later chapter.

Suppose with a class in a city school we begin the work by taking up the problem—the very large problem—of supplying suitable water to people who dwell in a crowded community. New York, for example, needs more water than falls in the whole

Croton water-shed of 300 square miles. We must go as far as the Catskills to get a supply that is sufficiently abundant and sufficiently pure. The newspapers have set forth the facts and have said much about the engineering feats of this undertaking. The physics teacher must enable the future citizens to gain some idea of them. For example, the aqueduct must be carried under the Hudson, and in order to find a firm bottom it must go down 500 feet below the water level of the river. Now the weight of that water is about 15 pounds per square inch for each 34 feet of depth, or about 45 pounds per square inch for each 100 feet of depth and therefore 225 pounds per square inch at a depth of 500 feet. The method of determining the ratio of pressure to depth should be quickly shown by a lecture experiment and it will naturally be often referred to afterward so as to be well understood and not easily forgotten.

I once lived in a house where although the water pressure was great the pipes were so small that not more than one faucet could be used successfully at one time. If some one was drawing water in the laundry-tubs, it was useless to try to get water to flow from the faucet at the bath-tub. Show this fall in pressure along a water pipe as an increasing number of faucets are opened, by putting a pressure gauge on one of the faucets and noting its behavior as each succeeding faucet is opened. Quite incidentally, compare this with the fall in potential along an electric circuit as additional lamps are turned on, and later refer to this again when teaching electricity. This continual cross reference and repetition is of the utmost importance. We do not learn things once for all.

Now this fall in pressure introduces our most difficult problem in the distribution of city water. Although our aqueduct will be a larger tube than the subway tunnel, and our city water mains are as large as four or five feet in diameter, it will be very difficult to get the water to flow through them fast enough to meet the demand, and so pumps must be used to assist the flow. Our reservoir at High Bridge is about 150 feet above our basement. We go down there and read the pressure gauge and find it only 30 pounds per square inch when it would be 67 pounds if we were the only persons to draw water from the mains. So great is the draught of water from the mains that the fall of pressure

(fall of potential) is 37 (67–30) pounds per square inch in coming a little more than two miles. This fall in pressure has greatly increased as the city has grown up around us.

Within the building also the pressure on certain faucets has fallen from 8 pounds to 2 pounds per square inch because of the increase in the number of students and the consequent increase in the use of water.

It is quite similar with the electric conductors. The lamps of a certain lecture room once had 110 Volts of electric pressure, whereas now they frequently have not more than 105 Volts.

The time was when water would flow of its own accord at my lecture table on the fourth floor, but now it would seldom reach the second floor if it was not helped by a pump. The question of whether water presses equally in all directions will not be raised by the pupils at this point and had better not be injected too soon, but let attention be called to it incidentally a little later, not by the usual formal demonstration, but as a fact which has been demonstrated every time we have read the pressure gauge.

The physics teacher should teach hygiene quite as much as the biology teacher does, and he should teach chemistry whenever he gets a chance, whether he is nominally the chemistry teacher or not. The water filters demand his attention on all of these counts: What they mean to health; How they save the steam boilers; How they obviate plumbing difficulties; What alum is needed for; etc.

The physics teacher should teach about all sorts of mechanisms; as, for example, water meters, pressure gauges, etc. Buoyancy and Archimedes principle will be suggested somewhere about this time, and should have many lecture-room demonstrations and many individual laboratory experiments to make the matter a real experience. Specific gravity is not worthy of all the attention that is now given to it. It had better not be brought into this chapter at all, and in any case it should not be treated in the minute way which is usual. This exceedingly simple matter is generally obscured by being mixed up with buoyancy and paraffined blocks and lead sinkers and what not, which have no natural connection with it. Many days are spent in working on experiments and on arithmetical problems apparently devised as "busy work" to "hold down" the students lest they play.

I was conversing recently with an intelligent builder about how much a certain wagonload of Georgia pine weighed, and he settled the matter by sawing off a block one foot long from a timber which was four inches square at the end, and weighing it. He found that the block weighed five pounds, and from this he quickly calculated the weight of his load. I remarked that he had incidentally found the specific gravity of the wood to be about three-quarters, and he said, "Well I should never have suspected that. When I studied physics we made that a very complex matter which I never understood."

I suggested to him that the fact that a cubic foot of water weighs 62.5 pounds and that spruce timber is usually about half as heavy, while granite and most other kinds of rock are about 2.5 as heavy as water, would be very useful to remember. For instance, this enables us to quickly calculate that a granite paving block 12 x 6 x 4 inches must weigh about 26 pounds, and that 200 of them would make a heavy load for a team of horses on a good road.

Some reader has by this time queried whether our intention is to amuse and entertain the pupils and to relax their work. My purpose is to get more work and more intelligent work than we find now in our school laboratories. If the work is of absorbing and compelling interest, so much the better. I like to see high-school pupils work. They like to work. Three-quarters of all the pupils who enter the high schools of this country drop out during the course because they are tired of loafing and want to go to work. Give them something worth while to do and they will remain in school to work.

In order that we may examine the action of pumps, traps, "back-air" pipes, pressure tanks, hydraulic elevators, injectors, gas meters, etc. etc., we need to get an appreciation that air has weight and exerts pressure much as water does, also that it expands indefinitely if pressure is removed from it. One hundred and fifty years ago people were just as curious about the atmosphere and its properties as we are now about radio-activity. Public lectures upon the subject were crowded. It took a long time for people to appreciate the fact that they were living in the midst of an atmosphere which had weight, occupied space to the exclusion of other matter and in general behaved very much like

water. Teachers to-day forget that their pupils require a long time to arrive at a working knowledge of these facts. They need many closely related experiences to render the knowledge real. A single experiment, a brief statement, is not enough. To show by a lecture experiment that air has weight and to tell the pupils that a cubic foot of the air that surrounds them weighs about an ounce and a quarter is well worth while, but the real truth of the matter will not be appreciated until the subject has been attacked many times and on many sides. The pupils need some physics readers or perhaps leaflets. Let me attempt to write here a sample chapter in the hope that many others will be persuaded to take up this sort of authorship until the material for teaching physics becomes as rich as that for teaching history and English now is.

The Air

Looking from the window of my lecture-room I see powerful elm trees rocking in the wind. Certainly to bend them so far would require the power of many horses. How could anything by pushing against them move them so greatly unless it had a considerable weight. By roughly estimating the number of cubic feet I calculate that the air in this lecture-room weighs two tons; and with my anemometer I find that the wind is blowing forty miles an hour at present, and even while I am saying this a large limb has just been torn from the trunk of one of the trees. What might one expect if, say, the two tons of air which is in this lecture-room should move at the rate of forty miles an hour and strike against anything. If I roll these two rubber balls, which look alike to you, upon the floor and each comes in contact with the leg of a chair, you will readily infer from what you see that one is a hollow ball while the other is solid, for one is deflected from its course without moving the chair while the other carries the chair with it some distance. So when you see a freight car moving down the track to couple with another, you infer whether it is loaded or empty by the way it moves and by the power of its blow when it comes in contact with the other car. That is, our experience has taught us to feel that the damage which a moving body can do by collision depends very much upon its weight. This is why one might be willing to catch a light ball thrown at him when he would avoid a heavy one. But catching

ball suggests another consideration. One is willing to catch a ball thrown slowly when he would avoid one thrown swiftly, and we instinctively conclude something about the velocity of the wind by the work it will do. Hence I found its velocity by means of this little windmill with a cyclometer attached, called an anemometer. When we speak of the wind's blowing hard we are apt to think only of its velocity, and I suppose it would be natural to say that a forty-mile wind was blowing twice as hard as a twenty-mile wind. The fact is, however, that a forty-mile wind will push four times as hard against things as a twenty-mile wind does. Some definite figures will add to the interest of this study. When smoke ascends straight we say there is no wind. When the flags are just stretched out the wind is blowing ten or twelve miles an hour. It is not difficult to estimate a twenty-mile breeze by noting the movement of the smaller branches of trees, and a thirty-mile wind by noting the movement of the larger branches of the trees, and a forty-mile storm wind by the swaying of the whole trunks of trees. If one compares his estimates with the testimony of the anemometer for a time he will soon become quite adept. A ten-mile breeze will give .5 pounds per square foot of wind pressure for sailing. A twenty-mile breeze will furnish 2 pounds per square foot. A thirty-mile wind will give 4.5 pounds and a forty-mile gale will furnish 8 pounds. When you estimate the number of square feet in your sail and think of the number of pieces of lead ballast you are carrying it readily appears a dangerous wind for small boats. When the College was first built we had six window panes which were too large for their thickness to withstand the wind pressure and one after another they smashed in until finally we saved the last of them by putting a sash across the middle. Our leaded glass windows are all of them more or less concaved by the wind pressure. The wind lifts buildings from their foundations, uproots trees, piles up great snow banks and great sand dunes, raises mighty waves with their tons of water *because air has weight.*

I should like to have you go with me and see a fly wheel in our engine-room. The rim of this wheel is moving at the rate of sixty miles per hour. Its surface is so smooth that you can let it rub against your hand without injury, in spite of its high velocity. Standing near it, as you now are, you feel a wind that makes you

hold on to your hat. The air is very still in all the rest of the engine-room. Now stand one side while I pour some water upon this wheel, and you note that the wall of the room is now getting spattered with that water. One reason why the surface of that wheel keeps so bright and clean is that the wheel itself throws off from its surface every bit of dirt which might come in contact with it. It is in like manner throwing off the air in constant streams. Does not this make one realize that air is a fluid like water, having weight—although invisible? There must also be friction between it and the wheel. I'll pour upon this wheel a steady stream of water and let you notice it leaving the wheel on the line of a tangent. You may like to remember that the so-called " centrifugal force " causes things to fly away on a tangent rather than on a line leading directly from the center. If you try to use a sling you will need to know this fact. Or to state it still more in accordance with our natural experience, when the water gets in motion it tends to move in a straight line rather than around a curve. This fly wheel suggests our ventilating fans, which we must look at while they are standing still. One of these wheels reminds one of a water-wheel. Can you not imagine such a wheel well inclosed and revolving rapidly backward throwing water from a lower reservoir up the " water fall " back into the mill-pond? See Figure 1. If the wheel were perfectly smooth at its rim some considerable amount of water would be thrown up the flume by reason of the friction. But it must be perfectly evident that the flanges across the rim of the wheel serve still better to keep the stream of water from slipping backward. The result is that the stream of water tends to keep more nearly the velocity of the wheel—just as a chain belt working over a cog wheel does less slipping back than a leather belt.

Figure 1 represents fairly the construction of the first one of our ventilating fans which we come to on our trip about the building. A represents the intake of outdoor air, and B the ducts which distribute the air to the rooms of the building. Of course we shall return to this often when studying the heating, the filtering and the humidifying of this air. The other ventilating fans about the building differ from each other in minor points, but chiefly they differ from this in that they take in the air at C instead of at A. The inlet ducts bring the air to the centre of the wheels along

the line of their axles. The wheels are of skeleton construction and the air is thrown out at B as before, simply because it has weight and tends to fly off on a tangent. It requires eighty-horse power to run the ventilating fans which push the air through the Horace Mann School building. This means that air has weight and offers resistance to motion. It costs about $50 a day just to push the air along, which fact seems appalling when looked at in that way, but that is only five cents a day for each pupil; and when we consider that 14,406 persons in New York State died

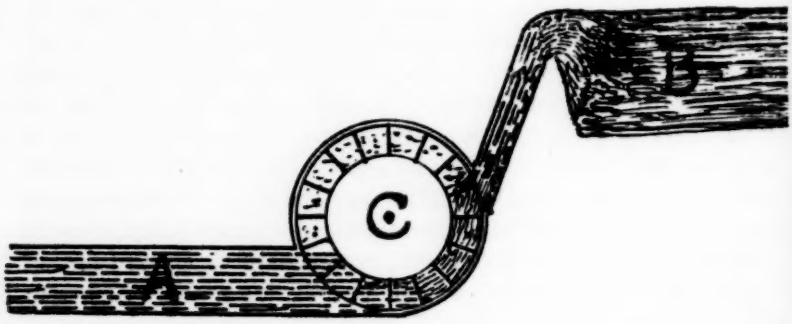


FIG. 1.

of consumption in the year 1907—that is, they died for want of fresh air—we must be willing to spend five cents a day for fresh air for each pupil in school.

Figure 1 also explains the construction of a "rotary" pump, a form of pump very much in use now not only for moving water but air, as particularly in the case of vacuum cleaners, one of which we will examine next. The hose is attached at A for "suction" or at B for blowing.

It must be evident that the stream of air is driven on by the *weight* of the air behind rather than by any such unthinkable thing as a *pull* or "suction." What the wheel, or pump, does

is to push the air from before it and the weight of the atmosphere moves the air in from behind to keep the space full. We are at the bottom of an ocean of air, and we may best appreciate this condition by imagining ourselves at the bottom of an ocean of water, because it appeals to our senses more directly. If we did live at the bottom of an ocean of water 34 feet deep, the water would press upon us with the same weight that our atmosphere now presses. By means of this pressure gauge I will show you that the pressure of our atmosphere is 15 pounds per square inch. Of course the air is pressing upon all sides of the wheel of the vacuum cleaner and when the wheel moves it drives a stream of air exactly as it would water if submerged in that. We shall return to the vacuum cleaner again to study several features about it. But let us now recall an experience you may have had while riding in an automobile or an open trolley car. Let us suppose a quiet day, when the smoke rises straight upward (not, by the way, because it is without weight but because the air is heavier than it and pushes it up). Let us imagine, I say, a quiet day when there is no wind, and we will start our automobile at the rate of ten miles per hour. We are now pushing our way through this quiet air and we feel a resistance of half a pound per square foot. The effect is the same as it would be if we stood still in a ten-mile breeze. A small flag which we carry stands out in the same manner as it would in such a breeze. Now let us increase our speed to twenty miles per hour and hold our flag with two hands across our line of motion. We are now pushing against the air with a force of two pounds per square foot. At forty miles an hour we push eight pounds per square foot and at sixty miles per hour we push eighteen pounds per square foot, which splits our flag. If we could make it one hundred miles per hour we should feel the pressure of fifty pounds per square foot exactly as many persons have experienced it in a hurricane. This experience, upon reflection, makes one feel that air has weight and occupies space which it does not yield to other bodies without resistance.

A windmill operates because air has weight and pushes against it. If the windmill is 25 feet in diameter a fifteen-mile per hour breeze develops one-horse power. The propeller wheel of an aeroplane drives the plane forward because in its motion it pushes against the air, which offers the necessary resistance, even as

water offers the necessary resistance to the propeller of a steam boat. The aeroplane lifts itself and its machinery and its passengers because its planes meet with the necessary resistance from the air as they cut it at an angle. The rising of a balloon must be looked upon as direct evidence that air has weight. The dirigible balloons which went up near the College a few months ago each contained about 7500 cubic feet of hydrogen. This pushed 7500 cubic feet of air out of its place. A cubic foot of air weighs 1.28 ounce, and it is about fourteen times as heavy as hydrogen. Hence the 7500 cubic feet of air displaced weighs about 544 pounds more than the hydrogen and therefore pushes the hydrogen up with that much force. Hence the bag of the balloon, the car, the engine, the man and his baggage, all together equalled in weight not far from 500 pounds. Think how the fact that air is matter is illustrated by the inflated foot ball, the pneumatic tires of automobiles, air mattresses and cushions, air cushions in door checks, air brakes, air guns, caissons, diving bells, machinery of all sorts moved by compressed air acting like steam. But lastly think of liquid air which is merely ordinary air reduced by cold and by pressure to about 1-800 part of its normal volume and which weighs a little more than water.

The following is a portion of a lecture by James Ferguson, F.R.S., on the "Spring of the Air" delivered some one hundred and fifty years ago. It is presented here as a good example of how the subject should be taught to-day—namely, by presenting the same phenomenon in many different ways.

To Show the Elasticity or Spring of the Air

14. Tie up a very small quantity of air in a bladder, and put it under a receiver; then exhaust the air out of the receiver; and the small quantity which is confined in the bladder (having nothing to act against it) will so expand itself by the force of its spring, as to fill the bladder as full as it could be blown of common air. But upon letting the air into the receiver again, it will overpower the air in the bladder, and press its sides almost close together.

15. If the bladder so tied up be put into a wooden box, and have 20 or 30 pound-weight of lead upon it in the box, and the box be covered with a close receiver; upon exhausting the air out of the receiver, that air which is confined in the bladder will so expand itself as to raise up all the lead by the force of its spring.

16. Take the glass ball mentioned in the fifth experiment, which was left full of water all but a small bubble of air at top, and having set it with its neck downward into the empty phial *a a*, and covered it with a close receiver, exhaust the air out of the receiver, and the small bubble of air in the top of the ball will expand itself, so as to force all the water out of the ball into the phial.

17. Screw the pipe A B into the pump-plate, place the tall receiver G H upon the plate *c d*, as in the twelfth experiment, and exhaust the air out of the receiver; then turn the cock *e* to keep out the air, unscrew the pipe from the pump, and screw it into the mouth of the copper vessel C G (Fig. 15), the vessel having first been about half filled with water. Then open the cock *e* (Fig. 11), and the spring of the air which is confined in the copper vessel will force the water up through the pipe A B in a jet into the exhausted receiver, as strongly as it did by its pressure on the surface of the water in a bason, in the twelfth experiment.

18. If a fowl, a cat, rat, mouse, or bird, be put under a receiver, and the air be exhausted, the animal will be at first oppressed as with a great weight, then grow convulsed, and at last expire in all the agonies of a most bitter and cruel death. But as this experiment is too shocking to every spectator who has the least degree of humanity, we substitute a machine called the lungs-glass in place of the animal.

19. If a butterfly be suspended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhausted, though the animal will not die, and will continue to flutter its wings, it cannot remove itself from the place where it hangs in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.

20. Pour some quicksilver into the small bottle A, and screw the brass collar *c* of the tube B G into the brass neck *b* of the bottle, and the lower end of the tube will be immersed into the quicksilver, so that the air above the quicksilver in the bottle will be confined there, because it cannot get out about the joinings, nor can it be drawn out through the quicksilver into the tube. This tube is also open at top, and is to be covered with the receiver G and large tube E F, which tube is fixed by brass collars to the receiver, and is close at the top. This preparation being made, exhaust the air both out of the receiver and its tube; and the air will, by the same means, be exhausted out of the inner tube B C, through its open top at C; and as the receiver and tubes are exhausting, the air that is confined in the glass bottle A will so press by its spring upon the surface of the quicksilver, as to force it up in the inner tube as high as it was raised in the ninth

experiment by the pressure of the atmosphere; which demonstrates that the spring of the air is equivalent to its weight.

21. Screw the end C of the pipe C D into the hole of the pump-plate, and turn all the three cocks *d*, G, and H, so as to open the communications between all the three pipes E, F, D C, and the hollow trunk A D. Then, cover the plates *g* and *h* with wet leathers, which have holes in their middle where the pipes open into the plates; and place the close receiver I upon the plate *g*: this done, shut the pipe F by turning the cock H, and exhaust the air out of the receiver I. Then, turn the cock *d* to shut out the air, unscrew the machine from the pump, and having screwed it to the wooden foot L put the receiver K upon the plate *h*; this receiver will continue loose on the plate as long as it keeps full of air; which it will do until the cock H be turned to open the communication between the pipes F and E, through the trunk A B; and then the air in the receiver K, having nothing to act against its spring, will run from K into I, until it be so divided between these receivers, as to be of equal density in both; and then they will be held down with equal forces to their plates by the pressure of the atmosphere; though each receiver will then be kept down but with one-half of the pressure upon it, that the receiver I had, when it was exhausted of air; because it has now one-half of the common air in it which filled the receiver K when it was set upon the plate; and therefore a force equal to half the force of the spring of common air, will act within the receivers against the whole pressure of the common air upon their outsides. This is called transferring the air out of one vessel into another.

22. Put a cork in the square phial A and fix it in with wax or cement; put the phial upon the pump-plate with the wire cage B over it, and cover the cage with a close receiver. Then, exhaust the air out of the receiver, and the air that is corked up in the phial will break the phial by the force of its spring, because there is no air left on the outside of the phial to act against the air within it.

23. Put a shrivelled apple under a close receiver, and exhaust the air; then the spring of the air within the apple will plump it out so as to cause all the wrinkles to disappear; but upon letting the air into the receiver again, to press upon the apple, it will instantly return to its former decayed and shrivelled state.

24. Take a fresh egg, and cut off a little of the shell and film from its smallest end, then put the egg under a receiver, and pump out the air; upon this, all the contents in the egg will be forced out into the receiver, by the expansion of a small bubble of air contained in the greater end, between the shell and film.

25. Put some warm beer into a glass, and having set it on the pump, cover it with a close receiver, and then exhaust the air. While this is doing, and thereby the pressure more and more

taken off from the beer in the glass, the air therein will expand itself, rising up in innumerable bubbles to the surface of the beer; and from thence it will be taken away with the other air in the receiver. When the receiver is nearly exhausted, the air in the beer, which could not disentangle itself quick enough to get off with the rest, will now expand itself so as to cause the beer to have all the appearance of boiling; and the greatest part of it will go over the glass.

Put some warm water into a glass, and put a bit of dry wainscot or other wood into the water. Then, cover the glass with a close receiver, and exhaust the air; upon this, the air in the wood having liberty to expand itself, will come out plentifully, and make all the water to bubble about the wood, especially about the ends, because the pores lie lengthwise. A cubic inch of dry wainscot has so much air in it, that it will continue bubbling for near half an hour together.

Compare this rich treatment of an interesting and important subject with the present practice of confining the instruction upon it to a single laboratory exercise to prove that P x V is a constant, leaving the pupil without any idea that Boyle's law is a matter of daily experience. Verily Franklin is quite right when he says: "My experience is, most emphatically, that a student may measure a thing and know nothing at all about it and I believe that the present high-school courses in elementary physics in which quantitative laboratory work is so strongly emphasized are altogether bad. * * * I believe that physical sciences should be taught in the secondary schools with reference primarily to their practical applications. * * * I cannot endure a so-called knowledge of elementary science which does not relate to some actual physical condition or thing * * * either you must create an actual world of the unusual phenomena of nature by purchasing an elaborate and expensive equipment of scientific apparatus, or, you must make use of the boy's everyday world of actual conditions and things."

Physics, as it is taught to-day, furnishes abundant material for an answer to Dr. Butler's question, "Is the present-day student brought understandingly and with ample introductory explanation into a new subject, or is he hurled into it and left to flounder helplessly until, not comprehending, he turns from it in disgust?" (*Educational Review.* Vol. 38, p. 519.)

Since Ferguson's time the world has made mighty advances in utilizing the "Spring of the Air," but in the matter of instructing the youth on that point we have gone backward. Why do we not show them the "pressure tank" connected with the hydraulic elevator which is perhaps in the school building? The last time we looked at ours, the pressure gauge stood at 90 pounds and the water gauge enabled us to estimate that the volume of the air had been reduced to about one-sixth of its normal volume. While we watched it the pressure rose and fell and the volume changed inversely—exact measurements upon this law are out of place in high school. So are all gas measurements with corrections for pressure and temperature changes. To show the relationship in round numbers is quite sufficient. A high-school pupil ought indeed to be taught the folly of one's saying that his bicycle tire burst because it was set in the sun. He ought to know that it would require a rise in temperature of nearly 500 degrees F. to double its volume if the pressure remained constant. He ought to know that a balloon did not "fall into the river because the chilly air of the river contracted its gas"; but to verify, with the usual ado, the accuracy of the laws of Boyle and Charles is out of place in the high school, not because the exercise is too difficult but because it crowds out things of much more importance. The high-school pupil should know that gas is measured for commercial purposes without reference to these corrections, and he ought to be able to estimate how insignificant the corrections would be in his gas bills, if they were made.

A similar illustration of how principles of physics may be well taught by calling attention to a large number of familiar experiences is to be found in Dr. Neil Arnott's book on "Natural Philosophy" written eighty years ago as follows:

Action and Reaction

If a man in one boat pull at the rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes, and resistances, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be

balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and meet; but the little one would perform a greater part of the journey, in proportion to its littleness.

A man in a boat pulling a rope attached to a large ship, seems only to move the boat; but he really moves the ship a little, for a thousand men in a thousand boats, pulling simultaneously in the same way, would make the ship meet them halfway.

A pound of lead and the earth attract each other with equal force; but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion of the earth is of course as much less than this as the earth is weightier than one pound, and is therefore unnoticed. Strictly, however, it is true, that even a feather falling lifts the earth towards it, and that a man jumping kicks the earth away.

A spring, unbending between two equal bodies, throws them off with equal velocity; if between bodies of different magnitudes, the velocity is greater in the smaller body, and in exact proportion to the smallness.

On firing a cannon, the gun recoils with as much motion or momentum in it as the ball has; but the momentum in the gun being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece will hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow guns, retards her motion; by firing from the stern she quickens it.

A ship firing a broadside, heels or inclines to the other side.

A vessel of water suspended by a cord hangs perpendicularly; but if a hole be opened on one side, so as to allow the water to jet out there, the vessel will be pushed to the other side by the reaction of the jet, and will so remain while it flows. If the hole be oblique, the vessel will turn round constantly.

A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steam-boat may be driven by making the engine pump or squirt water from the stern, instead of, as usual, moving paddle wheels. There is a loss of power, however, in this mode of applying it, as will be explained under the head of "Hydraulics."

A man floating in a small boat, and blowing strongly with a bellows toward the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

A sky-rocket ascends, because, after it is lighted, the lower part is always producing a large quantity of aeriform fluid, which, in expanding, presses not only on the air below, but also on the rocket above, and thus lifts it. The ascent is aided also by the recoil of the rocket from the part of its substance, which is constantly being shot downwards.

He was a foolish man who thought he had found the means of commanding always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern. The bellows and sails acted against each other, and there was no motion; indeed, in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man using an oar, or a steam-engine turning paddle wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force by the re-action of the water.

And a bird flying is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick, may be considered as compressing a spring between the earth and the end of his stick, which spring is therefore pushing up as much as he pushes down; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as if he were pressing with his stick.

Thus an invalid, on a spring plank or chair, who causes his body to rise and fall through a great range, by a trifling downward pressure of his hand on a staff or on a table, and thus obtains the advantage of almost passive exercise, is really lifting himself while he presses downward.

When a child cries, on knocking his head against a table or a pane of glass, it is common to tell him, and it is true, that he has given as hard blows as he has received; although his philosophy, attending chiefly to results, probably blames the table for his head hurt, and his head for the glass broken.

The difference of momentum acquired in a fall of one foot or of several, is well known; the corresponding intensities of reaction are unpleasantly experienced by a man who, in sitting down, is quietly received into a chair, or who unexpectedly reaches the floor where he supposed a chair to be.

What motion the wind has given to a ship, it has itself lost, that is to say, the ship has re-acted on the moving air; as is seen when one vessel is becalmed under the lee of another.

When a billiard ball strikes directly another ball of equal size, it stops, and the second ball proceeds with the whole velocity which the first had—the action which imparts the new motion

here being equal to the re-action which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and is as follows: The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed together with half the original velocity; but, as they are elastic, the touching parts at the moment supposed, are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion in the other.

If a billiard ball be propelled against the nearest one of a row of balls equal to itself, it comes to rest as in the last case described, while the farthest ball of the row darts off with its velocity, the intermediate balls having each received and transmitted the motion in a twinkling, without appearing themselves to move.

Controlling Fires

During all the life of man upon the earth, down to even the last century, fires have been little understood. They have inspired awe and terror and have been objects of superstitious veneration.

It is to be noted that men know facts a long time before they acquire the habit of acting according to that knowledge. Do all people know that air makes the fire burn? How shall we interpret the following incident, which is typical of hundreds of others occurring daily?

"While preparing her husband's dinner on a gas-range in the kitchen of their home, Mrs. ——— placed the sleeve of her dress too near the gas flame and was soon a mass of flames. As her husband reached the kitchen door he saw his wife run out into the hall screaming wildly. She ran down the stairway, shedding flaming fragments of her dress as she went. The husband did not overtake her until she had reached the hallway of the first floor, and was trying to open the door to go into the street. He rolled her on the floor, and stripped the remnants of the burning dress from her body. In the meantime the pieces of burning cloth had ignited the stair carpet between the second and third floors, and the hall began to fill with smoke. The other tenants were aroused, and while one went to summon an ambulance another turned in an alarm of fire. At the hospital Mrs. ——— is said to be in a serious condition."

A most common headline in the daily news is *Burned in the Sight of Many.* Two recent accounts tell of women stepping upon

matches upon the sidewalk, and while their clothes were in flame, not one of the onlookers knew what to do except to call a fire-engine or a policeman.

Little children whose clothes have caught fire are seized in the arms of distracted mothers who run about with them doing nothing but fanning the flames.

We continue to build costly structures of kindling wood, on which as a matter of course we pay excessive rates of insurance, oblivious of the fact that a considerable number of these buildings become annually the funeral pyres of multitudes. Our annual loss by fire in the United States, including cost of fire departments and cost of insurance, exceeds two hundred million dollars, and, is equal to that of all other countries combined.

The art of controlling fires requires that one should know how to build them, to regulate them, and to extinguish them at will. A fireman in a large building may save or waste many times his wages according as he understands the control of fires. It is a case where beyond all doubt the most expensive men are the cheapest.

The management of gas and gasoline-engines requires first of all a knowledge of combustion. If each person had a practical knowledge of combustion, such as any person beyond the primary-school age may acquire, nine-tenths of the destructive fires would not occur, and half the fuel, now wasted by the ignorant stoking of stoves and furnaces, would be saved.

A course in chemistry may teach one to say "oxygen is a supporter of combustion" without adding anything to his stock of useful knowledge about combustion. He may increase his erudition by "O=16" and "Sp. gr.=1.1056" etc., without being any wiser to act in case of the house being on fire. Suppose we invert a bottle over a burning candle. The flame burns for a short time and then goes out. Lift the bottle, light the candle and replace the bottle. The flame is immediately extinguished. Before the experiment the bottle contained air, which consists of nitrogen, etc., 80 per cent., and oxygen 20 per cent.; after the experiment it contained nitrogen, etc., 80 per cent., oxygen 15 per cent. and carbon dioxide 5 per cent. The presence of the latter gas is shown by pouring a little lime-water into the bottle. Note that it turns the lime-water milk white. Air in which one-quarter of

the oxygen has been replaced by carbon dioxide will extinguish a flame. It will also extinguish life. Hence a lantern is lowered into old wells to determine whether it would be safe for a man to descend into them. The air which comes from one's lungs is very nearly like that in the bottle after the above experiment. A bottleful of air from the lungs will extinguish a candle flame.

From the beginning of history to the time of the Swedish chemist Stahl, in the latter part of the seventeenth century, fire was considered an element. For about one hundred years previous to the researches of the French chemist Lavoisier, in 1878, it was believed that fuels were composed of ashes and a ghostly thing called phlogiston. Combustion according to this theory was the art of decomposing the fuels and setting free the phlogiston. We now know that fuels in burning unite with the oxygen of the air, forming new compounds. For example, when we burn in an ordinary furnace 15 tons of coal the furnace also consumes about 32 tons of oxygen from the air, and pours out into the air about 44 tons of carbon dioxide gas, leaving behind about 3 tons of ashes. These figures, although not exact, are intended to convey two ideas: (1) that combustion is a union of oxygen with fuels, and (2) that the process neither destroys nor creates matter, but merely changes combinations of matter. The oxygen is quite as much fuel as the coal is. It is very fortunate that the steamer has to carry only about one-third of the fuel it must burn, and fortunate that by far the largest part of the products of combustion dispose of themselves. Merely to shovel the coal into the furnace and the ashes out is a sufficiently large task.

In the case of the candle, and also in the case of the coal, water vapor is produced as a product of combustion along with the carbon dioxide. It may be noticed that when the bottle is first inverted over the candle a slight cloud of moisture forms upon the cool glass.

Breathe into a wide-mouthed bottle and notice first the moisture gather upon the sides of the glass, and afterwards add lime-water to show the presence of the carbon dioxide produced.

Our foods correspond to fuels and we take in also oxygen as a food or a fuel. By a process analogous to combustion we cause

oxygen to unite with these foods producing water vapor, carbon dioxide and heat for our bodies.

When a bottle of oxygen is placed over a burning candle, the candle of course burns brighter and longer but goes out before all the oxygen is exhausted. The contents of the bottle now act as a fire extinguisher although it contains as much oxygen as ever. Part of the oxygen is now bound in chemical union with carbon from the candle, and the oxygen which is free does not constitute a sufficiently large portion of the whole to support combustion. The presence of carbon dioxide and water vapor may be shown as before.

As might be expected, many things burn vigorously in pure oxygen which burn but slowly or not at all in the air, since the air is greatly diluted oxygen. A thin strip of iron may be burned with great vigor in oxygen. The reddish-brown powder which will be found covering the sides of the bottle after the close of this experiment is iron rust. It weighs considerably more than the iron which was burned and the increase of weight represents the oxygen which was burned. Combustion and rusting differ only in the rapidity of the action. Combustion is rapid rusting, and rusting is slow combustion. Both are called oxidation and the products are called oxides. The oxidation of our foods in our bodies is slow—more like rusting than combustion.

We cover iron with various things to prevent the oxygen of the air from rusting it. It is covered with tin in the tin ware of the kitchen, with zinc in the case of "galvanized" iron, with nickel, with porcelain, with paint, with grease, with vaseline, etc.

Drop a match into a flask and warm the flask gently, the combustion of the match begins at its phosphorus end at a very low temperature. After the flame has gone out put the charred portion of the match into another flask and heat. It will be found to have a very much higher kindling temperature than before, but nevertheless it has a kindling temperature. Before matches were invented about one hundred years ago, people were greatly troubled to start a fire. It was so difficult to raise fuels to the kindling temperature that generally they preferred to keep a "seed of fire" over from one time to another, and would usually borrow fire from their neighbors rather than go to the trouble

of starting a new one, which must be done by striking sparks with a flint and file and igniting tinder.

Explosive mixtures. Fill a 32-ounce narrow-mouthed bottle with a mixture of one part illuminating gas to five parts of air. Explode. Try other proportions and see how narrow is the limit for explosion. Note that in the case of an explosion the flame shoots through the whole mass instantly, each small portion of gas having next to it the oxygen necessary for combustion, and the burning of any part heats the neighboring parts to their kindling temperature. The kindling temperature of the mixture is about as hot as red-hot iron. Our experience teaches us that gas may leak into the air until the odor is very strong without its being possible to explode it with a flame. The fact is that if, in a mixture of gas and air, the gas constitutes much less than one-seventh or more than one-fifth of the mixture an explosion cannot take place. When the best proportions are reached the color of the flame during explosion is blue like that of a gas stove or a Bunsen burner.

In a 32-ounce narrow-mouthed bottle put four drops of gasoline; cork and let it mix with the air in the bottle and finally explode it. It will be found that a drop or two more or less will prevent the explosion. If less, nothing will happen; if more, the contents of the bottle will quietly burn at the mouth.

It is a marvel that a small two-horse-power marine engine may explode 1000 times a minute, when it is considered that for each explosion 4 drops of gasoline must be vaporized, the vapor must be thoroughly mixed with about one quart of air, the products of the previous explosion must be swept out of the cylinder, the fresh mixture must be taken in and compressed to about one-fifth of its original volume, and at the right instant an electric spark must be produced to raise a portion of the mixture to its kindling temperature. When one considers that all of this must be repeated one thousand times a minute, it is not strange that those who first proposed such a machine were considered erratic.

Try four drops of kerosene in place of the gasoline. It will not explode simply because kerosene is not volatile at ordinary temperature and, in spite of all we hear to the contrary, *kerosene lamps do not explode.* Now place the bottle containing four drops of kerosene and air in a kettle of hot water heated to at least

150 degree F., and at that temperature the kerosene will be found to be volatile like gasoline. After a few minutes it may be exploded. Gas stoves, Bunsen burners and Welsbach lamps are all devices for getting as near to the explosive mixture as possible without quite reaching it. When the mixture comes within the narrow limits of from 14 per cent. to 20 per cent. gas, the flame "strikes back." If the proportion of gas is much above 20 per cent. the flame becomes yellow and is not so hot. A larger supply of air is needed to give more perfect combustion and therefore more heat and no formation of smoke or other partially burned products.

The purpose of all draughts and dampers about stoves and furnaces is to regulate the supply of air and therefore the rate of combustion.

Teachers College is now burning 6,500 tons of coal a year. The engines and radiators call for a certain number of heat units per year. A little bad management of the fires might result in sending the products of combustion up the chimney half burned and require double the consumption of coal to produce the same result. The coal bill would then of course be increased about $15,000, and this is not the whole story, but enough for our present purpose.

In fighting a fire at its start, the one thing to do is to make it smother itself as the candle did in the bottle in our first experiment. An ordinary living room does not contain oxygen enough to burn up five pounds of wood. If the doors and windows are closed perfectly tight, a fire burning in a pile of dry kindlings in such a room will smolder for a time and go out precisely as the candle did in the bottle of the first experiment.

Some years ago I had the good fortune to hold in check for two hours a fire which had started upon a pile of kindlings in the basement of a school building full of pupils. The fire had a good start before it was discovered and the pile of kindlings was large. When the windows and doors were closed it smoldered down, almost checked by its own smoke, but enough air leaked into the room to keep a seed of fire, which started up into a lively blaze whenever the door was opened. There was no water except such as might be brought in pails. Having marshalled out the pupils, we gathered a good many pails of water in the room above

and prepared to cut a hole through the floor with an ax, knowing that the moment the hole was cut our water must completely extinguish the fire, or it would envelop the whole building in flames very quickly. The hole was cut, the water was successfully applied and the fire was extinguished, when it was found that although a considerable portion of the kindlings had been blackened, none had been thoroughly charred.

This experience should be compared with another in which a fire was discovered in the early morning in the basement of an apartment house. The maid in the basement rushed outdoors, leaving the door open, and shouted "Fire!" Those upstairs, when they attempted to descend, found smoke in the halls, and returned to open their windows and shout "Fire!" Before the fire department could arrive the building was in flames and eight persons were burned to death.

In an iron kettle, put some gasolene and set fire to it. When the flame is burning high, lay over it the pot lid. The fire is instantly extinguished because, no matter how combustible it is, it cannot burn without the requisite oxygen. Compare this with what happened not long ago. A woman was heating a pot of fat for frying crullers, when it took fire. She heroically seized the flaming pot by its bail and rushed to the sink and turned a stream of water into the burning fat, which of course went to the bottom, floated the fat and distributed the fire all over the kitchen.

A burning kerosene lamp was upset in the midst of books and paper piled upon a library table. No one was home but children. The oldest boy ordered his younger brothers and sisters to bring him all the rugs they could lay hold of. He stationed one child to keep the library door shut, while he, holding his breath, rushed in and laid a rug over the fire and came out to get a breath of fresh air. This performance was repeated until the fire was entirely out.

A little girl was playing on the lawn near where her brothers were celebrating the Fourth of July, when a firecracker, thrown into her lap, set fire to her dress. Her mother, who was looking on from the piazza, caught her in her arms and rushed with her into the house, where the fire was finally extinguished, but not until the child had been fatally burned.

A four-year old girl played with a match until it took fire, and in her fright she dropped it into her lap. No one was in the room with her at the time, but soon after her mother came in and found the child holding her dress gathered into a tight wad in her lap. When she induced her to release it she found a hole nearly a foot square burned out of the front of the dress, but no other damage done—not even were the little hands burned at all. She had many times been taught what to do if her clothes caught fire.

Most fire extinguishers are devices for producing carbon dioxide. With this they smother small fires by pouring into the atmosphere around them enough of the gas to reduce the proportion of oxygen below 15 per cent.

Streams of water, when thrown in sufficient quantity, as by fire engines, extinguish large fires both by cooling the fuel below its kindling temperature and by diluting the air with steam until the proportion of oxygen falls below 15 per cent.

One of the most effective ways of extinguishing a fire is to separate the burning fuel into small portions. Thus a considerable fire in a fireplace may be quickly extinguished by merely distributing apart from each other the burning embers. Their mutual heat is required to keep them above the kindling temperature. A shovelful of burning coals when taken from the furnace soon cool below their kindling temperature. The heat of the rest of the coal is necessary to keep them burning.

The fireman's ax and pick enable him to extinguish fire by separating in small pieces the burning parts of wood in floor or wainscot of buildings. When thus treated the wood soon falls below its kindling temperature.

Eggs

Problems to be solved by the pupils, mostly by experiments at home or in the laboratory.

1. May we determine the age of an egg by its specific gravity? Procure an egg laid within 24 hours. Write its date upon it and place a number upon it to designate it. Attach a thread to its large end by a little sealing wax. (If you cannot think why it should be attached to the large end rather than the small end, try it attached to the small end and continue with it so until you get an answer to the question.) Find the specific gravity of the

egg and weigh it each day thereafter for a month or six weeks. The egg may be kept in the laboratory or any living room all this time. See if you note any connection between the weight of the egg and the state of the weather each day. Some of our records are as follows:

Egg No. 6, Feb. 3, 1909. Wt. in air, 60.17 gms. Wt. in water, 3.35 gms. Sp. Gr. 1.059.

Feb.	4	Weight	59.94	Loss .23	clear
"	5	"	59.74	" .20	"
"	6	"	59.58	" .16	rainy
"	7	"	59.37	" .21	clear
"	8	"	59.25	" .12	damp
"	9	"	59.05	" .20	clear
"	10	"	58.88	" .17	humid
"	11	"	58.66	" .22	clear
"	12	"	58.45	" .21	"
"	13	"	58.30	" .15	stormy
"	14	"	58.14	" .16	"
"	15	"	57.97	" .17	"
"	16	"	57.82	" .15	"
"	17	"	57.59	" .23	clear
"	18	"	57.39	" .20	"
"	19	"	57.22	" .17	"
"	20	"	57.08	" .14	damp
"	21	"	56.93	" .15	"
"	22	"	56.78	" .15	"

On Feb. 22nd it floated on water. It was not dipped in water after Feb. 3rd. The date when this egg was laid was not known.

On clear days it lost more than on damp days.

This egg was broken on Feb. 24th and appeared to be perfectly fresh. It was allowed to dry naturally for two days and then was rubbed up to a powder, which is still in good condition (Jan. 12, 1910).

Egg No. 1, laid Feb. 25, 1909. Wt. 58.62 gms. Wt. in water, 6.06 gms. Sp. Gr. 1.115. On April 7th it weighed 52.46 gms. and floated on water. It lost an average of .15 gm. a day and required 41 days for it to become light enough to float. It was a yellow egg and apparently rather thick shelled. Grocers report that yellow eggs are preferred in the Boston market and white eggs are preferred in the New York market.

Egg No. 3. Wt. 53.72, Sp. Gr. 1.096. Average loss in wt. per day .17 gm. Floated in 28 days.

Egg No. 3. Wt. 44.89. Sp. Gr. 1.091. Average loss in wt. per day .1 gm. Floated in 34 days.

Egg No. 4. Wt. 62.06. Sp. Gr. 1.098. Average loss in wt. per day .15 gm. Floated in 37 days.

Eggs Nos. 1 to 4 were all laid within 24 hours of the beginning of the experiments with them.

These eggs differ so much in specific gravity (from 1.091 to 1.115) and the rate of evaporation from them is so different (from .11 to .17) that the age could not have been told at all closely by the specific gravity. This much however may be concluded from our experiments: all fresh eggs sink in water. Eggs which float in water are at least a month or six weeks old and have been kept in a dry room (except that infected eggs may spoil in a fortnight, generate hydrogen sulphide gas, and float). Eggs which are not infected (and few appear to be) do not spoil. They simply dry up. The air space appears at the big end and grows larger and larger.

The average egg must lose about 5 gms. before it will float, and this will require about five weeks in dry atmosphere. Eggs may be kept in moist atmosphere without losing weight, or put to soak in water and again recover weight which they may have lost.

Eggs are sometimes dipped in a diluted solution of water-glass to prevent evaporation and also to prevent infection. Some persons preserve them by dipping them in boiling water for a second.

A newly laid egg not only sinks in water but lies down flat on its side. After a week or two, if it is kept in dry air, the large end will rise a little when it is put in water, on account of the development of the air space in that end. In three or four weeks it will stand on its small end at the bottom of a tumbler of water. In four to six weeks it will float on water. An egg that is recently laid will sink in a solution of one teaspoonful of salt in a tumbler of water.

Put hydrochloric acid upon a piece of eggshell. Pass the gas into lime water. Put some white of egg into alcohol. Find the temperature at which the white of an egg coagulates. Heat some white of egg in a test tube with a strip of lead paper at its mouth. Action on silver spoons. Why does a dropped egg cook quicker than an egg in the shell? How does it happen that an egg put into boiling water in a small cup to cook four minutes is soft boiled while if put into a large vessel of boiling water for the same time may be well done? Dissolve out some of the fat from

the yolk of an egg by means of ether. Produce some black charcoal from the white of an egg. Weigh the white of an egg in an evaporating dish. Let it dry two days and when it is thoroughly dry weigh again to find out what proportion of it was water.

As good examples of how the teaching of physics and chemistry is being vitalized by some of the best teachers of to-day, I present the following papers which their authors have kindly furnished me for this purpose.

The Cost of One Candle Power Hour

(By Charles R. Allen, New Bedford, Mass.)

This experiment, as a group exercise, is useful in connection with class work on lighting devices as we find them in modern houses. While the apparatus seems rather expensive, it can often be borrowed, and has the advantage of bringing the class in contact with some commercial devices as actually used, as well as raising the question of cost.

The apparatus was mainly borrowed from the local company and consisted of a commercial house meter for electricity, a commercial arc lamp, a Cooper Hewett lamp, and a bank of six 16 c. p. incandescent lamps. These were connected so that the current for any one could be fed through the meter. A "test" gas-meter, a fish-tail burner, and a mantle burner were fitted in the same way for gas, while a candle and a small kerosene lamp, with scales and weights, came from the regular equipment.

The candle power of each lamp as claimed by the company, the cost of electricity, per K.W.H., of gas per 1000 cu. ft., of candles and of oil per pound, were given, and written on the board. Two pupils working together were asked to do one of the following:

1. Read meter, turn on the arc light fifteen minutes, read again. Repeat with the incandescent lamps. Repeat with the Cooper Hewett lamp. Calculate in each case cost of 1 c. p, for 1 hour in cents.

2. In the same way, get the rate of the fish tail burner and of the mantle burner, and make the same calculation.

3. Weigh the oil lamp, burn thirty minutes, and weigh again. From loss of weight calculate cost of 1 c. p. hour.

4. Do the same with a candle.

The results of these four sets of determinations were put on the board, and all pupils plotted a curve showing relative cost of 1 c. p. h. for each method. While the testing was going on, all pupils were given a chance to see the meters in operation, and the general principle of their construction was explained, without going into any great technical detail, descriptions of the electric lamps and of the meters were included in the written report of the work as exercises in English, and of technical description, and a wiring diagram was called for.

Of course, no great accuracy was obtained, or expected, but the results indicated the relative cost sufficiently to make a basis for discussion, while the study of the meter in operation gave some notion as to where the gas and electric bills come from.

High School Chemistry

(By Mr. Allen)

I have come to the conclusions set forth in this paper as the result of rather more than twenty years' experience in teaching chemistry in one high school in a New England city of moderate size. It seems to me that experiences so confined to one locality and class of pupils can lead to conclusions of no great general value; on the other hand, the frank setting forth of the results of experiences in many localities by many teachers, may lead to much good, and it is only with the hope that this contribution may be one drop in the bucket of general experience that I offer it.

Like all young technically trained teachers, my first teaching was an attempt to give, in diluted form, what I had been taught in the technical school—watered Freshman chemistry—but as the years went on, and I began to ask myself what I was doing, and what I was doing it for, I began to have doubts which grew stronger and stronger as time went on so that I found myself modifying my work more and more in a direction further and further removed from my original notions.

At present, I have come to look on the thing as it is here set down, but I do not offer it as a final state of mind, only as the point which I have reached at the present time.

My work as now carried on was based on the following convictions: (1) The average high-school student will never be a

chemist and will probably never directly use chemical knowledge. (2) The proper place to teach formal science is not the high school but the engineering school. What then can the high-school course in chemistry do for the pupil? It seems to me that it can do this:

(a) It can lay an apperceptive basis for the further study of chemistry in a formal way, if the student goes into an institution of higher learning.

(b) It can bring him in contact with chemistry as a field of human activity by showing him, to some extent, what chemists do, the nature of chemical problems, how they are attacked, and solved.

(c) As a field of human activity it has a history—this can be presented.

(d) It has its own workshop,—in this the pupil can be shown how to "take care of himself" in an elementary way.

In working along these lines, I finally came to the conclusion that the usual text-book of descriptive chemistry would not serve my ends, and, therefore discarded it, depending upon laboratory work, class discussion, and a reference library. I had forty weeks, six school periods a week. Of this time, the first twenty weeks were devoted to laboratory study of a few simple re-actions and compounds, following largely the general idea of the Harvard Syllabus, but not in detail, laboratory instructions were reduced to a minimum, and pupils were stimulated to work in their own way, even if it were a very crude one. Attention was always held on the question under investigation, and the value of the evidence obtained. Recitations were confined to a report on work done and a discussion of the bearing of the results on the point under discussion. No books were used and no general information was called for. In this way we worked through chemical change, oxygen, acids, bases, and salts. A study of salt gave the typical halegen acid and chlorine. Each step was fully discussed, and the general line of questioning was: what do you know? what did you do to find it out? what is your evidence? what would be the next step? how would you do it? Different pupils were encouraged to attack the same problem by different methods, and the results were compared and discussed in the class.

As an illustration, the following may be given. Pupils having found that acid re-acts with some metals, yielding a gas, made a comparative study of this gas and oxygen, thus getting evidence that it was not oxygen, but a new gas. (At the beginning of the course, they were given the usual tests for a solid, a liquid, a gas, as they could be applied by simple apparatus.) In studying this gas, they found it would burn; on discussion it was agreed that this product must be a fluid, probably an oxide of hydrogen. The next natural suggestion was to get it in quantity, which was usually done by playing the flame of a Bunsen burner on a flask with a circulation of cold water through it. (This was given the class as a handy way of getting the oxide.) They were then told that chemists always distilled an impure liquid before studying it (which gave the use of the still either in the conventional form, or in some form desired by the pupil). The distilled product was tested, was compared carefully with water from the tap, and so shown to have the same properties as the mineral water. The idea of analysis was then introduced, and by pulling out the oxygen by a hot metal, and identifying the oxide formed as similar to one already found by burning the metal in oxygen, and showing that the only other product was hydrogen, the composition was established.

During the first twenty weeks, while work of this kind was going on, the idea of nomenclature was introduced as needed, and pupils were encouraged to use symbols showing what they actually knew. Thus, water was written HO after they found that it contained hydrogen and oxygen only. Rudimentary equations were written in the same way, but only expressing what the pupils had actually found out.

After about twenty weeks of this sort of work, there was usually enough apperceptive basis to lead the students to feel the need of something and it was introduced at this point, illustrated by a series of rough semi-quantitative experiments showing how atomic weights were determined. Stress was laid on the fact that this work was illustrative merely, and students were asked to point out how this work would have to be modified to have any accurate value. Proper notation was now taken up as expressing the facts obtained by this work. For example, water is H_2O, not HO, because it has been analyzed, and also has a vapor

density of 9. In this I never found any difficulty in passing from the crude notation to the proper form. Pupils were now drilled in "translating" symbols and equations in terms of the facts shown.

The last ten weeks of the course were given to work in selected topics in applied chemistry, with free use of a reference library, largely in the form of papers prepared by different members of the class, often illustrated by experiment or lantern.

So far as any results could be tested they were as follows: pupils as a rule, were strongly interested in the work, seemed to have a real understanding of what they had been over, and those who took up chemistry in engineering schools and colleges did rather better than the average in the laboratory, and reported that the regular work in descriptive chemistry "came easy." On the other hand, measured by ordinary standards, they were woefully deficient in knowledge of general chemistry.

As this work was carried along, the historical side was brought out by essays, called for from time to time, historical or biographical.

All notes were written in the form of a report in which the student presented:

(1) A preliminary discussion, in which he stated exactly what he proposed to do, and what relation his work bore to the problem under consideration.

(2) A statement of his special method, with diagram, etc.

(3) Results or observations.

(4) Final discussion of results and bearing on the question under discussion.

These reports were fully discussed in the class, from the standpoint of expression, and of chemistry, and were all carefully looked over. Results and final discussions were always written in the laboratory, and the whole report was generally written there.

From this sketch, it will be seen that the characteristics of the course were: (1) Basing the work on illustrative semi-quantitative or on purely quantitative laboratory work, (2) the substitution of class discussion for the recitation, (3) no attempt to teach the conventional descriptive chemistry, (4) no attempt at purely instructive work, but a steady effort to keep the pupil

thinking, (5) considerable informal individual conference with pupils, (6) the use of the essay to acquaint the pupils with the literature of the subject, and the proper way of working up a given topic.

The Telephone

(By Calvin H. Andrews, South High School, Worcester Mass.)

The telephone as such has no place in the equipment of a physical laboratory, but if it is used as a means to an end rather than the end itself it can be made to be of great pedagogical value, for there is possibly no single instrument that involves the application of so many different physical principles as does the telephone.

The several parts of the telephone can be obtained at a small expense from the manufacturers of commercial instruments, and if the means at the disposal of the teacher will allow it, several pieces of each part should be obtained that two or more stations may be established.

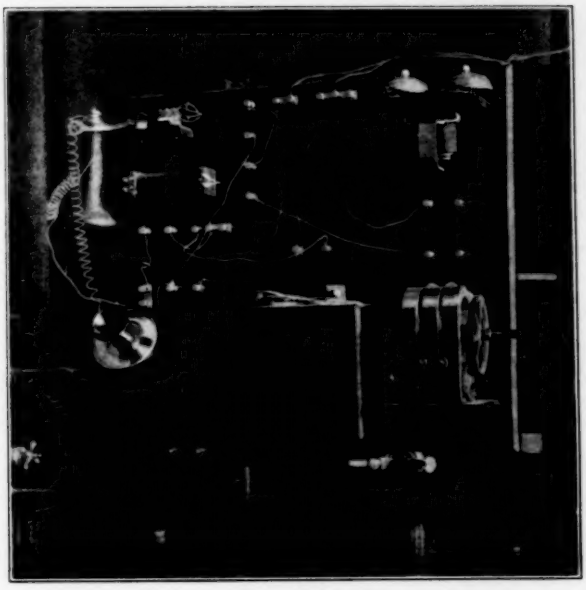
The following will be required for each set. A transmitter, a receiver, a battery of two dry cells, an induction coil, a polarized bell, a magneto and a fork switch. These parts should be mounted on a board and the terminals of each part brought to binding posts.

The cut shows a convenient arrangement on a board twenty inches square.

The apparatus can well be shown to the pupils early in the course in electricity, and briefly discussed. The several parts can then be studied in connection with the usual course in electricity, and when the class is prepared for the work a diagram of the connection is made and from this diagram the proper connections are made on the board. The test of the correctness of the diagram and the accuracy of the connections will be the ability of one set of pupils at one station to communicate with those of another station.

The study of the several parts will involve such questions as those which follow.

The Transmitter. By whom invented? How are the sound waves transmitted to the carbon contacts? How are the variations in current strength produced? Apply Ohm's Law.



This cut shows a convenient arrangement of the several parts of the telephone on a board twenty inches square.

The Receiver. What is the office of the permanent magnet? Of the coil? Of the soft iron plate? If the receiver is used as a transmitter what principle is involved? By whom was the receiver invented?

The Induction Coil. Why a necessary part of the telephone? What is gained by its use?

The Battery. Why necessary if the carbon transmitter is used? Why not necessary if the receiver is used as a transmitter? How is it protected from polarization by the fork switch?

The Magneto. How different from a dynamo? Why is the magneto thrown out of the circuit when it is not actually in use? How is this accomplished? What kind of a current is generated by the magneto?

The Polarized Bell. How different from the continuous ringing bell? What kind of current is necessary for the ringing of the bell? Draw the magnetic field of the permanent magnets of the bell.

The questions given above are merely to suggest the possibilities of the apparatus to illustrate in an interesting way the principles of Ohm's Law, induction, the alternating current, the direct current, etc.

Incidentally the pupils will acquire a knowledge of the telephone and will no longer regard it as an object of mystery.

Once having used apparatus such as this, the teacher will not rest until drops, jacks, plugs and cords, ringing and listening keys have been procured and a central exchange has been established.

Mechanical Efficiency

(By Mr. Andrews, Worcester, Mass.)

The principle of mechanical efficiency is commonly studied in the laboratory by the use of the inclined plane.

Although this experiment is simple, it is extremely difficult to prevent the pupils from confusing the idea of mechanical advantage with mechanical efficiency, especially if the former experiment immediately precedes the latter.

If, however, the subject of efficiency, which by the way is one of great importance, is taught by means of a small engine or a small electric motor, there will be a clear conception of the idea.

To perform the experiment, obtain a small working model of a steam engine. Such engines driven by air compressed in a small tank by a hand pump are obtainable for a small sum. Provide a simple rope brake by suspending a loop of stout cord from the hooks of two spring balances which are fastened to the ring of a lamp stand.

By raising or lowering the balances, the loop of the string may be made to press against the bottom of the grooved pulley of the engine with sufficient force to appreciably slacken the speed of the engine.

When the engine is in motion, one of the balances will oppose the motion, and the other will act in the opposite direction so as to assist the motion of the engine. The difference between the two balance readings will be equal to the resistance which is being overcome by the engine, and if this resistance is multiplied by the circumference of the pulley, the work done in one revolution of the wheel will be ascertained.

The following data taken from an actual experiment will indicate the method of performing the exercise.

Reading of balance No. 1	.48 lbs.
Reading of balance No. 2	.12 lbs.
Resistance overcome	.36 lbs.
Circumference of pulley	.96 ft.
Work done in one revolution	.34 ft. lbs.
No. of revolutions per minute	220
Total work done in one revolution	74.80 ft lbs.
Output of engine in horsepower	.0022
Gauge pressure	16 lbs. per in.
Length of stroke	.16 ft.
Diameter of piston	1 inch
Area of piston	.78 in.
Number of strokes	440
Input in horsepower	.026
Efficiency	8.4 per cent.

The number of revolutions may be easily counted if a speedometer is not available. In the calculation of the results it is assumed that the admission valve does not cut off the pressure, but that the full gauge pressure acts upon the piston during the full length of the stroke.

In the performance of this experiment the pupil will be required to measure length, area, force, work, power, pressure and efficiency. Incidentally, the pupil will acquire much information

concerning the working of a steam engine, and the work in mechanics will not be dry and uninteresting as it sometimes is. If an engine is not available, the matter of efficiency can be delayed and taken up in connection with the study of the electric motor, for a small motor is more easibly obtainable than is a small engine. In this case the output would be measured in exactly the same way as in the case of the engine. The input would have to be measured by the use of a voltmeter and an ammeter.

Four Lessons on Milk

(By W. G. Lewis, State Normal School, Macomb, Ill.)

1. Source. Goats, sheep, cattle. Commercial product in the United States is only from cattle.

Requirements of the Board of Health (New York City): Stables must afford at least 600 cubic feet of space for each cow. Must have at least two square feet of window for each 600 cubic feet of space. Milk from diseased cows must not be used. Any person having a contagious disease, or coming in contact with any person having a contagious disease, shall not handle milk. No adulterated milk shall be kept in the city. "Adulterated milk" means: Milk containing more than 88 per cent. of water. Milk containing less than 3 per cent. of fats. Milk, the temperature of which is higher than 50 degrees F. Milk from animals fed on distillery waste.

Composition: About 85 per cent. water; 5 per cent. proteid; 4 per cent. fat; 4 per cent. sugar; 2 per cent. mineral matter. The composition of milk is quite variable.

Many bacteria flourish in milk. Souring is due to bacteria which enter from the air. Cold retards the development of these organisms. Formaline and other preservatives also retard their development, but retard digestion as well. Heating milk to 160 degree F. for 20 minutes destroys all germs. This is called sterilizing. If it is heated to a higher temperature the composition of the milk is changed.

2. Cheese. The proteid can be separated from the rest of the milk to form cheese by any acid. In sour-milk cheese the lactic acid causes the curd to form. In the manufacture of American cheese rennet is used. Rennet is prepared from the inner layer of

calves' or pigs' stomachs, and its action on the milk is similar to the first stage of digestion.

As the curd sets in a jellylike mass, the fat, sugar, and water are caught and held by the proteid. The mass is then cut into small cubes and stirred about till the curd, by contracting, forces out the water and soluble constituents. The greater part of the fat is retained in the curd. The watery portion, whey, is then drawn off and the curd is salted and placed in the hoops of the desired size. These hoops are placed in a frame and the curd is subjected to great pressure to force out the remaining water. The cheese then must cure in a cool room until it is about forty days old.

Experiment (Demonstration). To about one-fourth of a pint of fresh milk add two or three tablespoonfuls of rennet. If the milk is at blood heat this amount of rennet will cause the curd to form in three or four minutes. The milk should not be disturbed while the curd is forming. When it is formed cut it into small pieces and stir gently. Heating gently helps to separate the curd and whey. The curd may then be forced into miniature molds to represent the hoops. (The excessive amount of rennet used to hasten the process imparts a strong odor to the curd.)

3. Butter. The fat of milk separates from the remaining portion if it stands in a cool room for a few hours. It may be separated in a few minutes by centrifugal force, if placed in a vessel revolving at a high rate of speed. The butter globules may be broken up by churning, and then the butter will adhere in a mass. Temperature and violence of churning greatly affect the length of time required. Cream should be at about 70 degrees F.

Many bacteria thrive in butter and eventually cause it to decompose till it is worthless as food. Cold retards the development of these bacteria. The addition of salt retards their growth and also makes it difficult to detect the decomposition of the butter either by taste or smell. For this reason many people prefer unsalted butter, for if it is unsalted it must be fresh.

Experiment (demonstration). Place half a pint of fresh cream in a crystalizing dish and allow warm water to flow around the dish till the temperature of the cream is about 70 degrees F. Beat it with an egg beater till butter comes. As cream varies greatly in the amount of time required for churning it is well to

test a portion before class, and if it takes more than three minutes, that which is to be used in class should be beaten till the butter is just ready to come.

Wash the butter with cold water till the butter-milk seems to be washed out. Mold the lump of butter into a ball and place in a cool room. For working the butter while washing it, use a wooden paddle which has been soaked in warm water. If it is desired to have the class taste the butter, a small portion may be served on crackers to each pupil.

4. Condensed Milk. Milk is condensed by boiling in a vacuum till it occupies from one-third to one-fourth of its original volume. The composition of the milk is not seriously affected except in regard to the proportion of water. A slight percentage of the mineral salts may be precipitated. About 50,000,000 pounds of condensed milk are annually imported into the United States.

Sweetened condensed milk is apt to prove detrimental to babies because the amount of sugar which has been added makes it necessary to dilute the milk to such an extent that the baby does not get enough fat. This difficulty is of course greatly increased if the condensed milk was manufactured from skimmed milk. If unsweetened, full-cream milk was used, it makes a very good substitute for fresh milk. In fact as it does not curd so readily it is easier for some stomachs to digest.

Experiment (demonstration). Warm two or three spoonfuls of milk (not to boiling) in a *round-bottomed* flask. Extract air with an air-pump until the milk boils up. Explain that this process, continued for some time, would reduce the amount of water to the desired proportion.

The Experience of One School

(By Howard C. Kelly, Central High School, Springfield, Mass.)

"All progress is history and biography." This article is a bit of the intimate personal history of one school—a school which, if our critics may be believed, has had fair success in maintaining educational ideals and achieving practical success at the same time. It tells of a changing point of view, and a gradual growth toward a more nearly satisfactory solution of the problem of first-year science.

When our new building was opened in September, 1898, large emphasis was being placed on the study and teaching of biology, particularly as a first-year subject. This is well shown by the division of rooms in the Science Department. At that time there were four rooms devoted to biology, one room devoted to chemistry, one room devoted to geology, and two rooms devoted to physics. Exactly one-half of the space allotted to science work was to be used for biological purposes. The course offered to the Freshmen, and required of them, was one in biology, so-called, and consisted of a half-year of zoology and a half-year of botany, two and one-half periods per week. This course was designed to arouse the interest and enthusiasm of the pupil, but in this respect it was not an unqualified success. It was worked out with great care, in accordance with the best educational theory and practice, but no great interest followed. In fact, there was a decided dislike and distaste for the subject, this being particularly noticeable among the boys. Occasionally a teacher of more than ordinary ability could make the work endurable, but as a whole the course failed to prove its right to an existence. Such work, especially the zoology, is by nature calculated to excite either intense enthusiasm or profound disgust—the enthusiasm being usually limited to a very few. Also, it deals with but one phase of human activity, and is, therefore, not well adapted to arouse general interest in a class of two or three hundred individuals whose tastes run to all sorts of extremes. *No one branch of science will ever arouse and hold the interest of a whole class,* a statement which may be applied with equal truth to all classes, large or small, with the possible exception of classes of rather mature age in elective subjects.

The biology course continued for six years in the new building, becoming more and more unsatisfactory, until at last it became very evident that some change must be made if science was to hold its place in the school. The unsatisfactory introduction to the science work was reacting unfavorably on the whole department. At this time Dr. Thomas M. Balliet, now of New York University, was Superintendent of Schools in Springfield, and with clear knowledge of existing conditions and a keen foresight, he and Principal William Orr formulated a plan for a

new course which should overcome the defects of the old, which should be constructive rather than destructive.

The purpose of the course was twofold: (1) *To give the pupil a broad general view of the whole field of science, at the same time arousing his interest and getting him awake to the possibilities of the work.* (2) *To explain to the pupil his everyday environment, showing him that the science of the school room and the science of the outside world are one and the same thing.* In scope the present course has outgrown even the expectations of those far-seeing men who planned its beginning, but it has steadfastly adhered to their ideals, and with uniform success.

At once a distinct improvement was noticed. The first year of the new work was largely, for various reasons, a mild course in physics with numerous practical illustrations, but the relief from the strain of the biology was evident, and there was every inducement to continue. The next year chemistry crept in to a greater extent, along with something of astronomy, the whole course becoming more and more related to the home all the while. And so it has continued, until now the whole family of sciences seem to have found their places in the scheme and to be working together in perfect harmony, the pupil himself being the centre around which all are grouped.

In accordance with our expressed purpose, the course does not have the same end in view as do most of our present courses in physics, chemistry, etc. There is no final examination to be met, no school for which to be prepared. Science is taught "not as a preparation for college, but as a preparation for life." Consequently the work is very strongly informational along general lines of interest, the lecture has a large place as a method of instruction, and quantitative work of the extremely "exact" sort is reduced to a minimum. To be sure, the element of quantity runs through it all and measurements of all sorts are being constantly made, but the elaborately exact measurement which kills interest while serving no useful purpose has been discarded.

The method of presentation can perhaps be best illustrated by an example, and a little of our work on foods has been chosen because it is fairly typical of the essential features which we try to keep in view. Nothing, perhaps, appeals to us with more force and directness than does our food, and the part of chemistry

which has to do with foods, their analysis and the detection of impurities, is most fascinating. Most people believe that adulteration of food and "pure food laws" are distinctly modern, that only in recent times have manufacturers and dealers been heedless enough of public welfare to introduce deceitful or harmless substances into the things we eat. As a matter of fact, however, fraud of this kind is extremely ancient. The oldest chemistry ever written contains something about food adulteration and methods of detecting it.

About seventy-five years ago there was found in a mummy case, which must date back to at least 2500 B.C., a roll of papyrus on which were written directions for adulterating flour with white clay, and for making wines out of water, acids, and coloring matter. Various careful directions were given in order that the fraud might not be detected by the consumer.

During the Middle Ages cases of adulteration became so frequent and so flagrant that very stringent means were taken to suppress it. Bakers who adulterated their food lost their bakeries as a penalty for the first offence; the penalty for a second offence was the loss of the right hand. In France a "pure food law" was passed in 1659 strictly prescribing the constitutents of bread and the processes to be allowed in bakeries. Even before this, in 1307, it was decreed by law that adulterated bread be broken up and distributed among the poor—a rather questionable method of procedure, it would seem. Our modern manufacturers, then, are simply following in the footsteps of the "good old times" when, at our request for bread, they give a stone—or something worse.

The early methods of detecting adulteration were extremely crude, and it is only in comparatively recent times that chemists have devised methods sufficiently delicate to insure detection. Our English ancestors were very much troubled because their ale was often adulterated. Sugar was frequently added, which they disliked. To determine whether the ale did contain sugar they were accustomed to throw a glassful on a bench and sit down in it. If on arising, after a little, their leather trousers stuck to the bench, the ale was known to contain sugar!

Information such as the above, collected from any and all possible sources, is given to the pupil in the lecture, along with direc-

tions as to methods of making tests. These tests are made at least once by the teacher that the pupil may have some idea of the manipulation and not work blindly. Then the pupil makes the tests, on materials brought from home where possible, each pupil testing, maybe, something a little different from that used by the others. This gives a rather wider range of results and helps in the drawing of correct conclusions. As an illustration of such a lecture and experiment the one on headache preparations follows. This has proved to be a very valuable feature of our work, though not more so, perhaps, than many of the other exercises which will be mentioned.

Headache Preparations. "Oh, how my head aches!" How very often we hear this exclamation, and how very often we, unfortunately, hear the reply of some friend, "Why don't you take So-and-so's headache powders? They cured my headache in ten minutes." Before we take such kindly meant advice, however, we ought to know a little about such headache "cures," of what they are made, what the after effects are going to be, how to tell the harmful from the harmless, and so on.

Most headache preparations, whether they be in the form of powder, tablet, pill, or liquid, contain a larger or smaller amount of one or more of the following substances; *acetanilid, phenacetin, antipyrine, caffeine,* and it is to these that the remedy owes its somewhat doubtful value. Acetanilid is the strongest drug used in headache powders. It is so powerful in its action that reputable physicians are growing more and more careful of its use, and many of them are discarding it altogether. It is one of the products of coal tar and has a certain quieting effect on the nerves together with a depressing effect on the spinal cord. Phenacetin and antipyrine are also taken from coal tar, and act just as does acetanilid on the person who uses them. They are all what the doctors call heart-depressants, which means that they slow up the action of the heart so that it does not pump so much blood through the body in a given time. In other words, they weaken the heart's action and that relieves the pain. Do you realize why, for example, our heads ache when we take cold? Our bodies are repaired by the blood, which, as it circulates, carries with it the material needed to repair waste. Now when anything is

wrong in any part of the body, the heart tries its best to make it right by sending more blood, and therefore more building material, to the diseased part. Of course more blood will go to all parts of the body at the same time, and the extra blood sent to the head produces a pressure which makes our heads ache. Then we take a headache powder, perhaps. The heart's action is weakened, the flow of blood is reduced, and the pain ceases. Notice, however, that the *cause* of the pain is not reached. A *cure* is not effected. The pain is relieved for the time, and that is all. This may even delay a final cure. The really sensible way would be to *seek the cause* of the disturbance in a disordered stomach, a weakness of the eyes, or maybe a cold. Then *treat the diseased part*, and the headache being only a symptom—one of Nature's danger signals—will disappear of itself. Nothing is ever gained, and sometimes all is lost, by treating a mere symptom.

The other drug mentioned, caffeine, is the same principle as is found in tea and coffee. How powerful its effect is may be guessed by the amount of wakefulness which is concealed for many people in even a small cup of coffee. Separated from the tea or coffee its effects is much more marked, and its action on the system much more powerful. It has a very stimulating effect on the nerves, brain and spinal cord. If used continually it produces what has been described by our government expert, Dr. Wiley, as "a state of chronic nervousness, with deranged digestion and impaired health."

To get relief by the use of any of these drugs is always accompanied by a serious risk. Many people can not stand the depressing action on the heart, and even death may follow. Very many cases have been recorded of deaths resulting from the use of headache powders, and that, too, from the normal quantity and not an overdose. Even when the results are not so serious it is seldom indeed that some injury does not follow. They are dangerous, as is well illustrated by this "caution" copied from the directions of a certain well-known powder. "We recommend that not more than two powders be taken within twenty-four hours." It must be a pretty powerful drug which requires a caution like that. Don't you think so? The safe rule is to take no such preparation without the advice of a physician. This same powder is advertised as "prescribed by a prominent physician in

his private practice." Very good, but does that mean that it is safe for *us* to use? That same doctor probably prescribed strychnine as a heart stimulant for some of his patients, but would it be wise for us to buy and use strychnine tablets whenever we have a pain in the side? We do not know its effect on us, nor do we know what amount would be proper. We are taking a very great chance in attempting to prescribe for ourselves.

Besides the danger of depressing the heart's action too much, there is the other danger of forming the drug habit. These particular drugs are particularly liable to produce that result. Each time the powder is taken it seems to have less and less effect, so either a larger quantity must be used or it must be taken more frequently. The person gets to depend upon it and the final result is very likely to be a drug habit as binding as that of alcohol or opium, and quite as terrible in its effects.

Finally, any drug which produces such a powerful effect in such a short time is dangerous to use except by a physician's advice. Ask any doctor if this statement is not a true one. Notice that this is not a condemnation of the drugs. They are useful and have their place, but that place is in the hands of a reputable physician who knows how to use them.

The Pure Food Law requires that such preparations shall be correctly labeled, so it is a rather easy matter for us to know just what we are getting. Read carefully the label of any such preparation and then avoid it if it contains a dangerous drug.

To sum up the whole matter, if the label on any preparation says that it contains: *Acetanilid* (or phenylacetamide, or antifebrin); *Phenacetin* (phenine, phenedine, phenetidin, acetphenetidin, or para-acetamido-phenetol); *Antipyrine* (sedatine, parodyne, anodymine, phenazone, or phenylone); *Caffeine* (theine, methyl-theobromine, or tri-methyl-xanthine), it means that there is present a powerful and dangerous drug. There are other names also, but the ones given are the most common.

A very simple test is sufficient to determine whether a powder is safe to use. Place a small quantity of the powdered sample in a dry test-tube, and add an equal quantity of powdered zinc chlorid [$Zn\ Cl_2$]. Heat, slowly at first, then strongly, holding a splint of wood in the fumes which arise. After these fumes have ceased rising, examine the splint and if it is colored red, yellow,

or both, the powder is unsafe to take without the doctor's advice. Slightly moistening the splint before use is sometimes advised, but is not necessary.

The following are a few of the different headache preparations now on the market which are good to test: Orangeine, Garfield Headache Powders, Dr. Kohler's Antidote, King's Curene, Shac, Bromo Seltzer, Antikamnia, Sherman's Headache Cure, Eureka Headache Capsules, Pyrofebrin Tablets, Capsiols, Moore's Headache Discs, Capudine, Phenyo-caffeine, etc., etc. The headache preparations put up by the druggist themselves and usually called "our own" are equally good to test, being usually compounded of the same things as the advertised article contains. Many of them have been found to be even worse.

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During the year other things, such as milk, butter, coffee and spices, are tested; dessert powders, jellies, gelatines, candies, etc., are examined for coal tar dyes; vanilla and lemon extracts are made, and lists of pure foods of many sorts are compiled. The pupils enter heartily into the scheme and the diversity of the substances tested is usually limited only by the knowledge of the teacher.

It must not be inferred from the above example and statements that the course is simply an indiscriminate mixture, nor should it be concluded that only the unusual attracts us. The backbone, so to speak, of the whole course is physics, real live physics, taught in such a way that its connection with life may be clearly seen. We do not talk much about hydraulics, it is true, but we do have a good deal to say about the city water supply system. The word pneumatics may never be used, but because the particular point of interest is a system of ventilation, it is none the less pneumatics. But, using the examples of hydraulics and pneumatics, water and air have a chemical side which can not easily be neglected, and thus there is an easy and natural transition from one division of science to the next. The real unifying influence, however, is the daily life and experience of the pupil as he connects the things he sees with the work being done in the laboratory.

This course appears to us to be valuable for several reasons: (1) The interest and enthusiasm of the pupils have been gained,

because science thus presented appeals to them as worth their while. (2) As a direct result of this increased interest and enthusiasm, the proportion of the school enrolled in the Science Department has largely increased, and that in spite of the fact that the school is distinctly classical. (3) Each year there have been numerous instances of very helpful effects on the life and habits of the pupils and of their parents. (4) The flexibility of the course has enabled it to be adapted to each changing condition, a thing impossible to obtain if a fixed line of work is demanded.

Finally, let one thing be emphasized. This work is not so much a *course of study* as a *method of instruction* which may be applied with equal success, we believe, to any and all sciences.

Carbon Dioxide

(By Messrs. Thompson and Klock, Beverley, Mass., High School, First Year Science Course)

Experiment XI. Object. *To find a third gas in air and to study it,—carbon dioxide.*

Apparatus and Chemicals. Eight-inch test-tube, two-holed rubber stopper, two pieces of glass tubing, lime water, two bottles of oxygen gas from gas holder, charcoal, magnesium ribbon, combustion cup, forceps.

Method and Results. (1) Take the test-tube and the stopper and adjust the glass tubes, one just through the stopper, the other reaching below the surface of the lime water well down below the bottom of the test-tube. Apply suction to the short tube. Draw air carefully through the apparatus but do not blow. Note change in the lime water.

(2) Take each bottle of oxygen and burn charcoal in it until all burning ceases. What compound has been produced? Into the first bottle pour lime water and shake. Note the change. Compare this product with that produced by drawing air through lime water.

Into the second bottle, introduce burning magnesium ribbon. What two products do you see? What does this show regarding the composition of the gas that produces a white substance with the lime water?

Make a drawing of the test tube apparatus used to detect the presence of carbon dioxide in the air.

A solid substance formed in a liquid by the addition of a gas or another liquid is called a precipitate.

Questions for Study: (1) What is produced when air is drawn through lime water? (2) What is a precipitate? (3) What causes the change in the lime water, a solid, a liquid or a gas? (4) How do you know? (5) What is the composition of the product in the bottle after charcoal is burned in the oxygen? (6) How does the result of drawing air through lime water compare with the result of shaking the product of burned carbon with lime water? (7) What two products result when magnesium is burned in the second bottle? (8) When magnesium burns, what is the color and the composition of the product? (9) This shows that the gas in bottles one and two is made up of what two elements? (10) What is the composition of the third gas in the atmosphere? What is the name of this gas?

History. Van Helmont, about 1600, collected from burning wood, from fermentation and decay, a gas which would suffocate animals and extinguish flame. This gas was carbon dioxide. Lavoisier was, however, the first to explain its real nature.

Occurrence. Carbon dioxide exists uncombined in the air to the extent of 4 parts in 10,000 parts of air or in per cent., 0.04 per cent.; and this apparently small amount is of very great importance in nature. It exists combined in marble, limestone, coral, shells, and chalk. In some localities, such as volcanic regions, it issues in great quantities from the earth and many spring waters carry large amounts of it in solution. It collects in unused wells, mines, vaults, and cisterns.

Preparation. It can be prepared by burning any substance containing carbon or by the action of an acid on limestone. The latter method is the better for most purposes.

Properties. It is a colorless gas, with slightly pungent odor and a sharp prickly taste. It is neither a combustible nor a supporter of combustion. It is heavier than air and that is the reason why it collects in caves, wells, and mines.

Uses. The uses of carbon dioxide are many and important. Those mentioned here are classified under four different heads.

(1) It is used to prepare soda water and so-called mineral spring waters. For this purpose, it is usually compressed into liquid form in iron cylinders from which the carbon dioxide is passed into common water. Vichy, seltzer, apollinaris, and Saratoga waters are all examples of water charged with carbon dioxide. It is carbon dioxide that gives beer its foam and champagne its sparkle.

(2) In the chemistry of cooking, carbon dioxide, made by the yeast during fermentation, makes the bread rise and become porous; and similar results may be obtained by using baking soda and baking powders. All kinds of pastry, except a few, owe their lightness and porosity to this gas.

(3) Fire extinguishers make use of carbon dixoide in putting out fires; this use depends upon the fact that carbon dixoide is a non-supporter of combustion. The gas is produced by the action of sulphuric acid on sodium bicarbonate. You can see an extinguisher of this sort on each floor of this building. The tank is full of a solution of sodium bicarbonate; at the top of the extinguisher in this solution is a bottle containing concentrated sulphuric acid, and provided with a stopper opened by means of a screw operated by hand on top of the extinguisher. In case of fire, the machine is inverted and the stopper of the bottle opened, thus allowing the acid to mix with the bicarbonate and produce carbon dioxide that mingles with the water and is delivered under pressure. To stop the action, turn the extinguisher right side up again, and with the screw replace the stopper in the bottle. If it has been used but a short time, there is usually enough acid and bicarbonate left in it to use again without recharging.

(4) Relation of carbon dioxide to life. Plants use carbon dioxide for food just as we use bread or sugar. Carbon dioxide is just as much a food for the plant as grass is for the cow; indeed all the carbon found in combined form in plants has come from the carbon dioxide taken in it by the plant. And since the whole human race would starve and disappear from the earth if it were not for plant life, it is highly important for us to study this carbon dioxide which plants depend on for their existence.

Plants breathe in air containing carbon dioxide through openings on the under side of the leaf and in the presence of sunlight,

with the aid of chlorophyll, the green coloring matter of the leaf, they break up carbon dioxide much as the magnesium ribbon broke it up in the last experiment. The carbon dioxide is broken up into oxygen, which is breathed out, and carbon which, in the presence of water taken up from the soil by the plant, is immediately converted into sugar, starch and various other materials of the plant.

Carbon dioxide is constantly being poured into the air in enormous quantities, from chimneys as the product of burning coal, from animals as a product of breathing, and from decaying substances as a product of decomposition. Why is it, then, that the quantity of carbon dioxide in the air does not increase to such an extent that animals suffocate and die? The answer has already been given. Plant life is using up carbon dixoide as fast as it comes into the atmosphere; even in winter when plant life does not exist to any extent on the northern continents, the wind, which is stronger at that time than at any other time of the year, circulates the atmosphere so thoroughly that the plants of the southern continents can do the work. In this way a constant balance is preserved throughout the entire year.

The Cycle of Carbon in Nature

Carbon passes through a complete natural cycle from the plant to the animal and through carbon dioxide back to the plant again. Plants by means of the energy from the sun, take carbon from carbon dioxide and with water make it into sugar and starch in the plant. A cow eats the plant and the carbon of the sugar and starch may pass into the fat of the milk and finally into the butter. Man eats the butter, which, when digested, gets into the blood and this serves to carry the carbon in the form of some of its compounds to every part of his body. Here an important change takes place.

Air contains oxygen. Man takes into his lungs air, from which the blood absorbs the oxygen and carries it all over the body just as it carries the digested food. In the process of life, this oxygen combines with the carbon of the food taken in and forms carbon dioxide which is breathed out into the air by the lungs. Then the plant takes the carbon dioxide from the air again, thus completing the cycle of the carbon.

The cycle of carbon may be summarized as follows: Plants take in carbon dioxide, keep carbon and give out oxygen. Thus the sun's energy is stored up in plants.

Animals eat the plants, take the carbon into their systems, and at the same time the oxygen of the air. The carbon and oxygen unite to form carbon dioxide, which is returned to the air. This union of carbon and oxygen gives out the stored-up energy of the sun as the heat and the activities of animals.

Carbon Dioxide in Nature

(1) At Herste, Germany, from borings made in the earth in 1894, 40,000,000 liters of carbon dioxide escape daily. It is 99.84 per cent. pure. By 1897, 10,000 grams were being liquefied daily. The origin of this carbon dioxide is probably due to the action of some of the salts of silicic acid on limestone at great depths in the earth.

(2) At certain places such as Saratoga and Selters, natural spring water comes to the surface of the ground highly charged with carbon dioxide. From such sources, we obtain such waters as Saratoga, seltzer, apollinaris, and vichy.

(3) At the Grotto del Cane, near Naples, in Italy, carbon dioxide issues in quantity from the ground. Here it forms a layer on the bottom of a small cave. When tourists arrive there, a man enters the cave with a dog. The man whose head is high above the level of the gas does not notice it, whereas the dog that accompanies the guide, is immediately overcome when placed on the floor. Of course, the little dog is revived at once and is ready for another demonstration when more tourists arrive.

(4) At Death Gulch in the Yellowstone Park, and near the Lake of Laach, in the so-called Valley of Death, in Java, large quantities of carbon dioxide issue from fissures in the earth. Animals often wander into these valleys and are overcome and die.

What Fuel Shall be Used for the Chafing-dish?

(By Mr. W. G. Whitman, Salem Mass. Normal School, formerly Ethical Culture High School, New York City)

The purpose of this series of experiments is to determine the relative economic values of ethyl alcohol, denatured alcohol and

wood alcohol when burned as fuel in the fount of the chafing-dish under the usual conditions of use.

One liter of water is put into a one-liter chafing-dish and a weighed quantity of alcohol is burned. If the one liter of water is warmed to the boiling point before the alcohol burns out, it is replaced by another liter of cold water. The heat absorbed by the water is calculated and considered as the useful heat available. The following tables have been taken from a pupil's record:

Fuel	Ethyl Alcohol	Denat. Alcohol	Methyl Alcohol
Weight of fount and alcohol	197.1 gm.	196.2 gm.	193.3 gm.
Weight of fount empty	106.5 "	106.2 "	106.3 "
Weight of alcohol burned	90.6 "	90.0 "	87.0 "
Water used and its change in temperature — 1 liter	22° to 97° C.	24° to 97° C.	22° to 97° C.
1 liter	22° to 95° C.	22° to 97° C.	22° to 84° C.
1 liter	25° to 84° C.	22° to 31° C.	
Heat absorbed by water	207,000 calories	158,000 calories	137,000 calories
Alcohol lighted at	9:05 A.M.	9:50 A.M.	2:00 P.M.
Alcohol burned out at	9:43 "	10:30 "	2:35 "
Time one filling of fount will last	38 minutes	40 minutes	35 minutes

1 gallon water=3785 gm. 1 gallon alcohol (sp. gr. .81)=3066 gm.

Fuel	Ethyl Alcohol	Denat. Alcohol	Methyl Alcohol
Useful heat from 1 gm. of fuel	2280 cal.	1760 cal.	1580 cal.
Amount of water which 100 gm. of fuel will warm from 20° C. to boiling	2.85 liters	2.2 liters	1.85 liters
Amount of fuel required to boil 1 liter of water	35 gm.	45 gm.	55 gm.
Useful heat produced per minute	60 cal.	44 cal.	45 cal.
Cost of fuel per gallon	$3.00	$0.50	$1.00
Cost of fuel per gram	$0.00096	$0.00016	$0.00032
Cost of boiling 4 liters of water	13.5 cents	3. cents	7. cents

The two most important considerations are economy of time and cost. The ethyl alcohol shows greatest economy of time since it produces the greatest number of calories of useful heat per minute. The great saving in cost, when denatured alcohol is used, is, however, for ordinary use, sufficient to more than outbalance the time saved by using the ethyl alcohol. If one wished to carry alcohol as a fuel on an extensive camping trip, the weight would be an important consideration. It will be seen from the table that when equal weights of fuel are considered, the ethyl alcohol gives more useful energy; but here the state of one's pocket-book and the size of his pack will have to be considered in helping to make a choice.

Fuels for Small Portable Stoves

(By Mr. Whitman)

There is a large demand for some means of producing heat in small amounts for heating and for cooking purposes. In the small city apartment, in the large country home, in the summer camp, in fact, wherever one lives, there is at times use for a small portable stove. In early fall and late spring when the winter furnace is not running, the small stove is used to take the chill from the air. In winter it may serve to give auxiliary heat in extremely cold weather. It may heat entirely a small room which is not connected with the regular heating plant. The small cooker is of inestimable value. It is convenient; can be started in a moment; saves fuel when only a small amount of food is to be cooked. It applies the heat just where it is needed and fuel is consumed only while it is producing useful energy.

The advantages to be derived from these stoves have made their use very common. It is therefore important that people should have a thorough knowledge of the management of them, of the efficiency of different fuels, and of the different types of stoves for the same fuel. It is also very important from the hygienic point of view that those, living in rooms heated by these stoves, consider the effect of the burning fuel upon the purity of the air of the room, especially when used, as is so often the case, in a small unventilated or poorly ventilated room.

The electric stove, where current is available, stands first, when cleanlinesss, ease of operation and hygienic value are considered. To determine whether the expense would make it prohibitive, tests may be made in the laboratory later in the course when the subject of electricity is taken up. We will eliminate the electric stove from our present consideration, in which a study is made of the three most popular stoves: those burning gas, kerosene, and alcohol.

In order to make a scientific study of the relative merits of these fuels, first of all, combustion and the quantitative relation between the fuel, oxygen of the air, and the products of combustion must be understood. The pupils have already had an elementary treatment of combustion in their general science course. They have studied it in this course as an important source of heat. They

now add to their knowledge of combustion by taking particular account of the burning of carbon, hydrogen and methane, and calculating the amount of air used and the amount of carbon dioxide and water vapor produced. They have studied about humidity, saturated air, dew point, the relation between capacity of air to hold water vapor and its temperature; the effect of high relative humidity upon health and comfort, the harmful results which come from condensation of moisture from saturated air, as the swelling of wood work, "steaming" of windows, rusting of piano wires, etc. This has prepared the pupils to understand the effects of the water vapor which is produced in the room as a product of combustion.

Gas Stoves. As a preliminary preparation, "A Study of the Bunsen Burner" is given as a laboratory exercise. In this the pupil finds out the reason for a luminous and non-luminous flame, the cause of a sooty flame, the kind of flame for most heat, for most light, why the Bunsen flame sometimes strikes back, danger from this and remedy. After this two types of stove are examined: one giving a luminous flame; the other of the Bunsen type.

Kerosene Stoves. The flat wick and central draft burners giving a luminous flame, the wick blue-flame burner, and the non-luminous blast flame types are compared.

Alcohol stoves. The "alcohol gas stove" has an elevated reservoir of alcohol. A wick from the bottom of the reservoir feeds the alcohol to the burner at a lower level. The alcohol is vaporized and issues from the burner as a gas. Another alcohol stove has the fount below the burner just as in the ordinary kerosene lamp. The wick is enclosed in a metal holder and never comes in contact with the flame. The wick holder is surrounded near the top by a priming chamber. A small pump extends in the fount. When the stove is to be lighted, a small amount of alcohol is pumped into the priming chamber and lighted. This heats the metal wick holder and vaporizes the alcohol in the wick. The vapor finds outlet in a series of small holes around the edge of the priming chamber. Here the alcohol burns and enough heat is taken by the wick holder to continue vaporizing the alcohol.

After the pupils are familiar with the different stoves, one for each fuel is selected and these are used to test the relative merits of the three fuels. The amount of fuel consumed in warming

the same weight of water through the same change of temperature is determined. The change in composition of the air is considered, taking account of the products of combustion.

The following data and equivalents are given the pupils for use in calculation and discussion of the subject:

The burning of	Requires		Produces	
	Oxygen	Air	Carbon dioxide	Water vapor
1 lb. hyrdogen	89.9 cu. ft.	432.6 cu. ft.	——	9.0 lbs.
" carbon	29.9 "	144.3 "	29.9 cu. ft.	——
" acetylene	34.5 "	165.9 "	27.6 "	0.7 "
" methane	44.9 "	215.3 "	22.5 "	2.2 "
" carbon monoxide	6.3 "	29.9 "	12.9 "	——
" city gas	44.2 "	212.9 "	12.2 "	3.4 "
" hard coal	25.9 "	124.4 "	25.1 "	0.3 "
" soft coal	27.5 "	132.4 "	23.0 "	0.4 "
" ethyl alcohol	23.4 "	112.0 "	15.5 "	1.2 "
" methyl alcohol	16.8 "	81.1 "	11.2 "	1.1 "
" kerosene	39.3 "	189.0 "	27.8 "	1.4 "

Gas	Weight of 1 cu. ft.	Volume of 1 lb.
Oxygen	0.089 lbs.	11.24 cu. ft.
Air	0.080 "	12.44 "
Carbon dioxide	0.122 "	8.17 "
Enriched water gas (city gas)	0.043 "	23.20 "

1 lb. water vapor saturates 5300 cu. ft. of air at 20°C. (68°F.). 0.000188 lb. water vapor saturates 1 cu. ft. of air at 20°C.

1 lb. = 453.6 gms. 1 gm. = 0.002204 lb. 1 cu. ft. = 28.3 liters.

The amount of fuel required to boil 2 liters of water is found by experiment, the time observed, and other items as given in table below are calculated. Cost is reckoned on this basis: kerosene, 13c. per gallon; denatured alcohol, 50c. per gallon; gas, 80c. per thousand cubic feet. The following table taken from pupils' reports is the average of four independent trials:

Fuel	Kerosene	Denatured alcohol	Gas
Amount of fuel required to warm 2 liters of water from 20° C. to 95° C.	94.15 gms.	132.14 gms.	4.77 cu. ft.
Cost	0.41 cents	2.11 cents	0.39 cents
Time required	25 min.	47 min.	20 min.
Volume of air used	39.3 cu. ft.	32.3 cu. ft.	44.9 cu. ft.
Vol. of carbon dioxide produced	5.72 "	4.53 "	2.68 "
Weight of water vapor produced	0.28 lb.	0.34 lb.	0.72 lb.
Volume of air this water can saturate at 20° C	1505 cu. ft.	1827 cu. ft.	3865 cu. ft.
Vol. of air of relative humidity 50% which this can saturate at 20° C.	3010 "	3654 "	7730 "

From a consideration of the above figures it may be concluded that if time and cost are considered there is not much choice between kerosene and gas. Although the gas has a slight advantage; the alcohol is surely outclassed. Less time is needed for care of the gas stove and it has the advantage of always being ready. The gas is the worst offender in taking oxygen from the air, using up 45 cu. ft. of air against 39 cu. ft. by kerosene. The carbon dioxide added to the air is not harmful in itself, but might become a source of harm if it increased enough to dilute the oxygen materially. The water vapor produced by burning gas is twice that produced by either the alcohol or kerosene. This is objectionable if the gas burns for a long time, for it will usually saturate the air and cause a deposit of water; although it might happen that the relative humidity in the room was low, then if the gas was burned but a short time, it would be helpful in raising the humidity up to the proper amount. If the ventilation were exceptionally good these objections to gas would be removed. If we were situated where gas was not available we would choose kerosene for fuel except for such use as the chafing-dish.

The experiment may be varied by finding out if the efficiency of the fuel is changed by rapid or slow heating. Metal tops, supplied with these stoves to be added when used as heaters, may be put on and tests made in a small closed room. Temperature change in the room is found and also the change in composition of the air. Moisture may be determined by a dew point method and the carbon dioxide by means of a Fitz Shaker or a Wolpert air tester.

One of the most significant facts which this whole discussion teaches is the urgent need of adequate change of air where these small stoves are used.

The Fireless Cooker

(By Mr. Whitman)

When water warmed over a stove reaches the boiling temperature, it is found to keep at that temperature. No matter how much heat be applied the temperature is not raised. When a substance is cooked by boiling in water, after the boiling tem-

perature is reached, additional heat need be supplied only to replace heat lost to the air or wasted in vaporizing water. The substance is warm enough to cook and if loss of heat already in the substance is prevented, cooking will go on and no more fuel need be burned.

In studying about conduction of heat, it was learned that there are many substances, poor conductors of heat, which are used to prevent loss of heat from a hot body and to keep heat away from a cool body.

For many years the Norwegians have been accustomed, after heating certain foods to the boiling point of water, to remove the dish from the fire and wrap it in a blanket or other poorly conducting material. One of the simplest and most convenient means is to pack straw or hay about the dish in a small box.

Fire is used only to heat the material at first; practically all the cooking is done after removal from the fire, hence the name "fireless cooker" is appropriate.

Even the best non-conducting materials will take some heat away from the cooker, so the temperature falls a few degrees right away and then very slowly. But there are many foods which will cook at temperatures below the boiling point of water, if the heat is applied for a longer time. The improved fireless cookers have the non-conducting material held permanently in place, leaving a space in which to set the hot dish of food. A cushion of non-conducting material is then used to cover it. The case supporting the hot dish and separating it from the non-conducting excelsior or hay is sometimes made of thin sheet metal. This gives rigidity to the wall and is better for sanitary reasons since it is more easily cleaned. It does conduct away some of the heat however. To make up for this loss a stone of same diameter as the dish and two to three inches thick may be heated to 300°C. to 400°C. and placed at the bottom of the space under the dish.

Such a cooker may be made by the girls of the class and if they have a little help they can put in the metal work. The use of the thermos bottle for keeping a hot body hot or a cold body cold suggests a similar use for the fireless cooker. Two of the girls

in the physics class this year made a fireless cooker and tested it for use as a cooker and as a refrigerator. The results of their tests are tabulated below.

	Time		Time in in hours	Temperature of water	
	at start	at end		at start	at end
Without the stone	3:30 P. M.	9:30 A. M.	18	88° C.	40° C.
With hot stone	2:30 P. M.	9:00 A. M.	18.5	100° C.	60° C.
With pan of ice in place of stone	10:30 A. M. Mon.	9:00A. M. Tues.	22.5	0° C.	7.5° C.
	10:30 A. M.	9:30 P. M.	35	0° C.	13° C.

These results show a sufficient saving of heat for cooking purposes. If a substance were put into the cooker, boiling hot, at 8 o'clock p. m., it would be cooked and hot enough to serve for breakfast at 8 o'clock a. m. the next morning. The tabulated results also show that it is a very efficient refrigerator. After these tests were made the fireless cooker was given to the girls of the domestic science department, who will test it in actually cooking different foods.

The fireless cooker should find a warm welcome in the summer camp. One can go off on an all day's outing and know that his dinner is cooking and will be steaming hot when he returns tired and hungry at night. It makes it possible to have things cooked for dinner without having a fire in the heat of the day. Not only for economy in fuel and time but for greater convenience, cleanliness, removal of steam and odors and improvement in quality and flavor of the food, does the fireless cooker deserve more extensive use than it now has.

HANDWRITING

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